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STUDY OF AIRCRAFT IN INTRAURBAN TRANSPORTATION SYSTEMS SAN FRANCISCO BAY AREA

Prepared by
THE BOEING COMPANY
Seattle, Wash.
for Ames Research Center

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16. Abstract

The study examines the nine-county San Francisco Bay area in two time periods (1975-1980 and 1985-1990) as a scenario for analyzing the characteristics of an intraurban, commuter-oriented aircraft transportation system. Aircraft have dominated the long-haul passenger market for some time, but efforts to penetrate the very-short-haul intraurban market have met with only token success. Yet, the characteristics of an aircraft transportation system-speed and flexibility-are very much needed to solve the transportation ills of our major urban areas.

The aircraft intraurban system is a technically feasible alternative to ground transportation systems. Although requiring some subsidy, it becomes socially viable where substantial commuter traffic exists at ranges of 10 to 15 mi (18.5 to 27.8 km) or more and where topographic features constrain ground travel. The general problem areas of community noise, air traffic congestion, ground transportation interface, pollution, and safety appear to have workable solutions.

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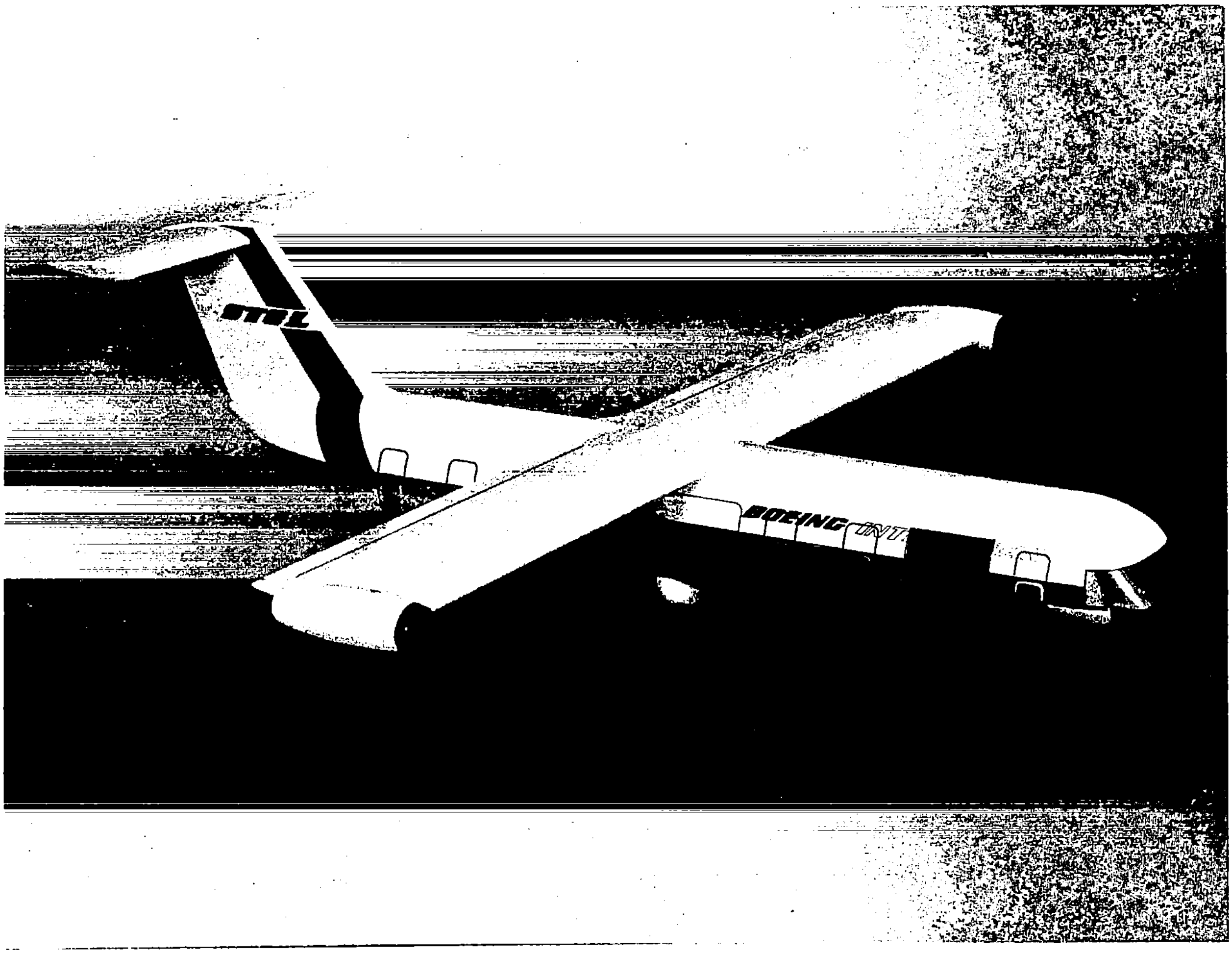
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FOREWORD

This study was performed by the Commercial Airplane Group of The Boeing Company. The Vertol Division provided the helicopter and tilt rotor technology and configuration data.

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In addition, valuable contributions were made by the following firms and organizations:

Metropolitan Transporation Commission (MTC), Berkeley, California (formerly BATSC/RTPC).—The detailed data on current and projected transportation demand within the greater San Francisco Bay area used in this study were developed by the MTC. The availability of this comprehensive travel data has allowed the study to be conducted on a level of detail much greater than would otherwise have been possible.

Bay Area Study of Aviation Requirements (BASAR), Oakland, California.—Mr. Walter E. Gillfillan, study director, has been most helpful in providing access to air transport projections developed for the BASAR study as well as guidance to other data sources.

Golden West Airlines, Inc., Long Beach, California and Los Angeles Airways, Los Angeles, California.—An appreciation of the trends in indirect costs of airlines operating at very short flight distances was obtained through the cooperation of these airlines.

Pratt & Whitney Aircraft Division of United Aircraft Corporation, East Hartford, Connecticut.—Mr. H. J. Remmer has been most helpful in providing data pertaining to the low-cost and low-maintenance engine.

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1.0 INTRODUCTION

This report presents a summary of the results of a study conducted by The Boeing Company under contract to the Advanced Concepts and Missions Division, Office of Advanced Research and Technology, National Aeronautics and Space Administration. Detailed results are presented in NASA CR-114347. The study contract, NAS 2-5969, began in June 1970 and was completed in March 1971. The study was conducted primarily by the Commercial Airplane Group at Renton, with rotorcraft technology and engineering being supplied by the Vertol Division at Morton, Pennsylvania.

The study examines the nine-county San Francisco Bay area in two time periods (1975-1980 and 1985-1990) as a scenario for analyzing the characteristics of an intraurban, commuter-oriented aircraft transportation system. Aircraft have dominated the long-haul passenger market for some time, but efforts to penetrate the very-short-haul intraurban market have met with only token success. Yet, the characteristics of an aircraft transportation system—speed and flexibility—are very much needed to solve the transportation ills of our major urban areas.

In August 1967, The Boeing Company completed the "Study of Aircraft in Short-Haul Transportation Systems," reference 1. That study examined the use of VTOL/STOL aircraft in short-range (50-400 mi–80-644 km) intercity transportation systems, all of which had had some form of CTOL air service for some time. The results showed that both VTOL and STOL aircraft could be economically viable over those ranges.

The present study of aircraft in intraurban transportation systems is concerned with ranges below those investigated in the previous study. This study will attempt to determine if the aircraft can contribute toward solving the transportation problems of major metropolitan areas and be economically viable in such an environment.

The current method of providing for the increased transporation demands in our major cities is to build bigger freeways, add rapid transit (such as the Bay Area Rapid Transit), or both. With freeways becoming less and less popular with amateur and professional ecologists, public transporation systems are being looked on with more favor. Local and national subsidies are available in varying amounts. The flexibility inherent in an aircraft transportation system and its freedom from community-disrupting ground corridors offer some possible improvements over ground systems.

2.0 OBJECTIVES

The principal objectives of this study are:

- Determine the technical,economic,and operational characteristics of a commuter-oriented aircraft intraurban transportation system.
- Determine the sensitivity of these characteristics to changes in the aircraft, market, and operation of the system.
- Identify key problem areas where additional research may result in significant improvement in aircraft transportation systems.

To this end, the study is concerned with the following tasks:

- Developing vehicles appropriate to the commuter-oriented transportation system.
- Establishing a level of technology in each design and operational discipline that is representative of a transportation system starting service in the 1985 period
- Establishing direct and indirect operating cost estimates for the vehicles that reflect the unique operating environment of very-short-range very-high-density commuter operations
- Identifying an air traffic control system concept to cope with the high density of civil air carrier, general aviation, and intraurban aircraft traffic
- Establishing possible terminal sites in the major sections of the Bay area considering aircraft type, flight frequency, ground handling and rapid turnaround, air traffic control, local terrain, alternate terminal use, compatible site and community land utilization, surface accessibility, and passenger convenience
- Establishing realistic passenger demand, mode split, fare structure, and route systems for a base-case transportation system about which sensitivities can be evaluated

The study is primarily oriented towards understanding the transportation system. The specific aircraft designs have not been developed to a high degree but are representative of possible concepts for such a system. Although five concepts were evaluated in the first phase of this study, detailed economic analyses have been completed on only one representative STOL and one VTOL in each time period. A high-speed VTOL, the tilt-rotor aircraft, was included in 1985 to understand the important parameter of cruise speed.

3.0 CONCLUSIONS

The aircraft intraurban system is a technically feasible alternative to ground transportation systems. Although requiring some subsidy, it becomes socially viable where substantial commuter traffic exists at ranges of 10 to 15 mi (18.5 to 27.8 km) or more and where topographic features constrain ground travel. The general problem areas of community noise, air traffic congestion, ground transportation interface, pollution, and safety appear to have workable solutions.

A number of specific conclusions can be drawn from the baseline systems and sensitivity studies described in the summary, section 5.0:

- The VTOL aircraft, although having higher operating costs, show generally superior total economics due to the reduced investment in ground facilities. The VTOL terminals are much smaller than the 2000-ft (610 m) STOLports due to the 3-min gate time used in the study. This low gate time allows a five-gate VTOLport, at less than 8 acres (3.2 hectares), to equal the capacity of a single-runway STOLport of 30 acres (12 hectares). In intercity systems where a gate time of 20 to 30 min is more usual, equal capacity STOLports and VTOLports are more nearly equal in size. Other factors must also be considered, however, in choosing between concepts. It is assumed in this study that all concepts are equally reliable. The level of technology and degree of development required is then another figure of merit for each concept. In view of the current operational status of STOL and VTOL aircraft, it would seem that this required development would be greater for VTOL aircraft in general and the tilt rotor in particular.

- The design field length analysis of the STOL aircraft shows this same relationship. As the field length decreases, the direct operating cost (DOC) increase is overshadowed by the decrease in ground facilities investment.

- The largest single item of cost in each system is the cash direct operating cost (DOC) of the aircraft. The cash operating costs, both direct and indirect (depreciation on aircraft and ground facilities not included), amount to 40% of the total system cost for the STOL aircraft and 60% of the total system cost for the VTOL aircraft. In most systems studied, revenue exceeded all cash operating costs, but, in no systems, were the excess aviation revenues sufficient to cover the cost of sinking funds (capital accounts for replacement of aircraft and terminals) and interest on the long-term debt. If federal funds are available for two-thirds of the total original investment, continuing local subsidy can be substantially reduced and in some systems eliminated.

- The absolute level of air traffic predicted in this study is subject to question due to general uncertainties associated with prediction techniques for passenger acceptance of a new mode of travel. The time/cost relationship used does, however, provide a reasonable interaction between system elements and the resulting passenger demand that is fundamental to the objectives of this study.

- Cruise speed (up to 250 kn–463 km/hr) is an important parameter even at the very short ranges of the intraurban system. This is demonstrated by the effect of technology on the 1985 helicopter where the cruise speed is increased from 170 to 210 kn (315 to 389 km/hr). This increased speed attracts more passengers, lowers DOC at longer ranges, increases productivity, and results in a 46% lower loss per passenger. For the STOL aircraft, reducing the cruise speed to 200 kn (370 km/hr) from 325 kn (602 km/hr) increases the loss per passenger by 24%. For cruise speeds above 325 kn (602 km/hr), the gain is negligible.

- While high cruise efficiency and low structural weight are still important to a very-short-range aircraft, the sensitivity of the gross weight to these factors is very much less than for an intercontinental aircraft. For the intraurban aircraft, the resulting cost/weight trades heavily favor those structural concepts in which some weight penalties are taken to reduce manufacturing cost and operating cost and increase reliability and maintainability.
- Propulsion systems with low maintenance and low manufacturing cost as prime design goals (allowing some increases in specific fuel consumption and weight) also show favorable trends in total system cost.

- Low gate times are very important to an intraurban system. They allow a reduced fleet size, lower ground facilities investment, and lower IOCs. The savings are much greater than the increase in the per-aircraft and per-gate costs necessary to achieve low gate times.

- The extreme peaking characteristics of a commuter-based system have a major effect on system operations and economics. The peaking predicted for this study increases cash operating costs by 10% and fleet size by 60% when compared to a system with a constant demand over an 18-hr day.

- The downtown ports, although the most costly, contribute the greatest amount of passenger demand and operating revenues. The service to the community is greatest here also in the form of relief to congested roads, bridges, and parking lots.

- The intraurban system is not economically feasible under current air traffic control (ATC) procedures and regulations. Some form of fourth-generation ATC must be introduced that will provide for reduced separation at busy STOLports and strategically controlled, time-synchronized operation. A large development effort is not necessary to achieve a satisfactory system for use within the geographic area of the study.

- It is difficult, if not impossible, to develop unit cost for cargo movement competitive with surface modes. As a result, system losses cannot appreciably be reduced by direct competition with ground transportation. Only where major system cost savings can be found for such items as high-value goods, and time-critical commodities, is some loss amelioriation possible. However, because the intraurban system will probably rely to some extent on subsidy, competition with other commercial cargo transportation systems might well be limited, except for public service such as mail.

- Community noise from intraurban aircraft, does not in itself seem to be sufficient justification for eliminating the aircraft system as an alternative to other modes of transportation. As long as the aircraft-generated noise exceeds the background noise level, however, some opposition will appear. To give the aircraft system a reasonable chance, substantial effort must continue in areas of research directed toward STOL and VTOL aircraft noise reduction.

- When the Bay Area Rapid Transit System, as it will exist in 1975, is added to the analysis of the aircraft system, those routes that are served by BARTD are dropped from the aircraft system. This results in a loss of 45% of the demand and an increase in the loss per passenger for the remainder of the aircraft system. It would appear that an optimum mix between ground and airborne transportation systems could be found. The ground-based systems are at their best over very short ranges serving very dense populations. The airborne system is at its best at the longer intraurban ranges, offering fast transportation to a much greater area, with the added ability of being able to respond rapidly to changing community needs.

- A logical STOL network would begin service with a STOLport as near downtown San Francisco as possible and serve terminals at other existing airports surrounding the bay, including the three major airports.

- A high-speed intraurban transporation system tends to expand the job opportunity area of the central business district. To the extent this is considered desirable, the aircraft intraurban system is a reasonably cost-effective method of accomplishing this purpose.

- Although the study was specifically for the San Francisco Bay area, many of the results can be applied to other large metropolitan areas. This cannot be done, however, by the use of simple demographic criteria (population, area/density ratio, etc.). Topographical barriers separating areas of high density have a substantial effect on the size of the intraurban system required.

4.0 RECOMMENDATIONS

As a result of this study, some key problem areas are identified where additional research or study would contribute significantly toward bringing about improved transportation systems. The intraurban aircraft can generally benefit from technical research on all VTOL/STOL aircraft. There are some items in the following list, however, that are particularly important to the intraurban system. The items are separated into two areas, those that are primarily technical and those that are primarily systems analysis.

- Technology
    - Community acceptance criteria for aircraft noise
    - Noise suppression techniques for all concepts
    - Landscaping and architectural techniques for shielding nearby communities from terminal noise
    - Design standards for VTOL/STOL intraurban aircraft
        - Maneuver and stall margins for powered lift concepts
        - Design field length rules
        - Control response and handling characteristics requirements
        - Attitude and acceleration limits for passenger acceptance
    - Autoflight—takeoff through landing   maximum safety,
    - Terminal and en route navigation   minimum weather delays
    - Air traffic control techniques and displays
    - Reliability and maintainability
        - Lift systems
        - Control systems
        - Landing and navigation systems
        - Propulsion system
    - Propulsion system dynamics and integration
        - Cruise mode for valveless augmentor wing
    - Advanced structures
        - Materials
        - Design concepts
        - Cost/weight trades at intraurban design ranges
    - Propulsion-lift/aerodynamic-lift trades
    - Gust alleviation for ride comfort, controllability, and wake turbulence
    - Rooftop STOLports
        - Turbulence
        - Emergency arresting equipment

- Systems Analysis
    - Modal-split techniques
        - Passenger preference factors
        - Value of time
    - Relative safety between competing modes
    - Intercity use of intraurban terminals
    - Relative total economic impact on community of competing modes of travel
    - Impact of possible local restrictions on use of automobile

- Strategic air traffic control simulation
  - Weather limitations
  - STOL traffic demands
- Optimum mix of air and ground intraurban transportation systems
- Political and ecological impact
- Specific off-peak utilization for intraurban aircraft in San Francisco Bay area
  - System benefits to high-value and time-critical commodities
  - Possible surface competition development
  - Passenger service to northern California urban and recreational areas

This study did not examine a large number of concepts but concentrated mainly on the analysis of a representative aircraft system. Some effort should now be undertaken to investigate many vehicle concepts for relative suitability in this area. Perhaps even more important, however, would be an in-depth analysis of one concept to investigate, in detail, certain areas of prime importance to an intraurban system such as: maintainability and reliability at minimum turnaround times; structural design concepts for minimum-cost vehicles; propulsion systems designed for low noise, maintenance, and manufacturing cost; etc. . .

5.0 SUMMARY

A summary of the major results in each area of the study is presented in this section. Expansion on each of these subjects can be found in the main body of the report.

5.1 STUDY TRANSPORTATION SYSTEM

The nine counties of the San Francisco Bay area, figure 5-1, are the subject of this intraurban transportation study. Shown on this map are the locations of postulated air terminals and their identification numbers, which are referred to from time to time in this report.

The terminals have been located as close to the passenger origin and destination (O&D) demand as possible within the constraints of noise and compatible land use, air traffic control (ATC) considerations, ground access, and weather considerations. In the suburban areas, existing general aviation airports have been used where possible, and service is provided to the three major regional airports.

The total daily travel demand for this area is shown in figure 5-2 for 1980 and 1990. These are aggregated trips from the area nearest one terminal to the area nearest any other terminal shown in figure 5-1. These travel data have not been estimated here, but are based on data supplied by the Metropolitan Transportation Commission (MTC) in Berkeley, California. The MTC data were based on comprehensive home surveys and cordon surveys in 1965 and expanded by them to 1980 and 1990 by detailed forecasting processes using many demographic features and historic data. The trip-demand data were supplied to this study in the form of a matrix of daily passenger trips between any of 291 analysis zones. These trips have then been grouped by a modal-split model into interterminal trips as shown in figure 5-2.

The decrease of travel demand with range is typical of a metropolitan area that includes commuter travel. The aircraft system is most suitable at the longer ranges of this trip demand, although some trip distances as low as 6 mi are considered.

5.2 CONFIGURATIONS AND TECHNOLOGY

Five major concepts representing both STOL and VTOL in three passenger capacities and two time periods have been analyzed in this study. The three best concepts in a nominal 100-passenger capacity are shown in figures 5-3 through 5-5. The two additional concepts, a conventional STOL and a jet VTOL are discussed in the configuration section (6.0). They were not included in the detailed economic analysis as initial results showed them to be less profitable, and time allowed only one representative VTOL and one representative STOL aircraft to be analyzed in depth. The tilt-rotor VTOL was included to show the effect of speed on system economics.

Two time periods are anlayzed in this study: a near term and a far term. The near-term aircraft are designed with today's technology with introduction of service to begin in 1975. The system analysis for these aircraft is based on the 1980 MTC travel demand, which represents a midlife point for the 1975 aircraft.

The far-term aircraft are designed using advanced technology applicable to an aircraft starting service in 1985. The system analysis for these aircraft is based on the 1990 MTC travel demand, which again represents the midlife for the aircraft.

The concepts all use the "European Train" compartment-type fuselage, with a door on each side of the airplane leading into a compartment with facing seats. Sensitivities are included later for more normal aircraft seating arrangements. The vehicles are designed with simplicity and low cost (both initial and operating) as the prime consideration, as cruise efficiency is of little importance at the operating range considered here. Tables 5-1 and 5-2 summarize the general characteristics of the concepts, and tables 5-3 and 5-4 present the weight summary for each concept for two typical design capacities. The gross weights are plotted against passenger capacity in figure 5-6, and the air trip time (block time) is presented in figure 5-7.

5.3 OPERATING COSTS

Both direct and indirect operating cost estimates are made as a result of component-by-component analyses of both the aircraft and the transportation system. Table 5-5 shows the total aircraft acquisition price and also breaks down the total price to airframe, electronics, and engines. The low prices are primarily a result of very simple structure (and hence manufacturing techniques) and a much larger than normal production quantity (2000). The production quantity is based on the assumption that if the system is feasible in the San Francisco Bay area it will also be feasible in many other major metropolitan areas around the world.

The cash direct operating costs (DOC) are presented for the 1975 concepts in figure 5-8 and for the 1985 aircraft in figure 5-9. They are shown as trip cost versus range rather than the more usual "cents per seat mile" in order to show the cost down to very short ranges. The depreciation of the aircraft is not included here because all investment costs are treated separately in the economic analysis. The steeper slope of the helicopter DOCs reflects the slower cruise speed of this concept.

For a typical range of 30 mi (56 km), figures 5-10 and 5-11 show a breakdown of the operating cost by major category. These figures also show the allocated depreciation (dotted lines) for one possible utilization of 5 hr/day (1550 hr/year).

The results of the component-by-component analysis of the indirect operating costs (IOC) is shown in table 5-6. Each cost category in the IOCs is related to the seven causal factors in coefficient form. The resultant equation, shown in table 5-6, has been used in the comprehensive computer analysis of each system. Table 5-7 compares the IOCs for the base intraurban system with other more familiar levels of service.

As with the DOCs, the IOCs do not include any investment costs or depreciation. The total ground system investment for the base STOL and base VTOL system are shown in table 5-8. These include all the costs for the aviation-oriented facilities required for the terminals. The cost of providing facilities for concession operators and excess space available for other rentals is assumed to be covered by their associated income. The maintenance facilities for the systems shown in table 5-8 require an additional investment of $19 000 000.

5.4 NETWORK ANALYSIS

The usual approach to the economic analysis of an aircraft transportation system is to estimate aircraft utilization, average load factor, and other important parameters based on the past history of such systems. The use of aircraft in an intraurban system has no such past history. The very short ranges and highly peaked and directional passenger demand of a commuter-oriented system make the estimate of important system parameters very difficult. The use of these estimated parameters then casts grave doubts on any results forthcoming from the analysis.

In this study, a comprehensive transportation network model is used that eliminates the need to estimate the important parameters of the system, thereby allowing greater confidence to be placed in the results. The network model takes aircraft passenger demand (as a function of time of day) for each link in the system and constructs a complete schedule of aircraft flights for one typical day in the system. The cash DOCs are summed for each flight, including any required ferry flights. The IOCs are calculated based on the causal factors developed in the model: number of terminals, departures, gates, passengers, etc. The aircraft and ground system investments are summed and the resultant annual interest costs and required sinking funds calculated. A detailed economic analysis can then be performed. Depreciation is accounted for by the sinking fund method of amortization, where interest-gathering capital accounts are set up for replacement of aircraft after 10 years and terminal facilities after 20 years.

The aircraft passenger demand input for the network model is obtained from a modal-split model that operates on the detailed total trip demand in the Bay area received from MTC. For each passenger trip, the time and cost for the auto trip are calculated and compared with the time and cost for the air trip. The auto trip cost is based on 40% single-occupant travel with 60% of these, or 24% of the total travelers, using total auto costs including depreciation and insurance in their mode comparison. The remainder of travelers see their auto cost as out-of-pocket incremental expense only.

The air trip cost is the sum of twice the incremental auto cost to the nearest terminal (kiss and ride), the air fare, and a 15-cent average bus fare at destination.

These relative times and costs are then compared and the passengers willing to take the air mode determined as follows:

- Where door-to-door trip times and costs are exactly equal, 50% of the travelers will take the air mode.
- Where door-to-door trip times are equal, no one will take the air mode if its costs exceed the auto costs by $2.00 or more.
- Where door-to-door trip costs are equal, everyone will take the air mode if they save 30 min or more of trip time.

A method of predicting passenger acceptance is included here for two important reasons: first, to show the sensitivity of this demand to changes in system variables (e.g., fare, terminal location, speed, gate time) and, second, to obtain the level of traveler demand for the air mode.

The base air fare used in the study is shown in figure 5-12. The resultant demand from the modal-split model for variations of this base fare are shown in figure 5-13 for 1980 and figure 5-14 for 1990. As the air fare is decreased, the air mode becomes attractive to the large number of short-distance travelers, causing the average trip distance to reduce also.

An example of the results of the network model using the 1980 passenger demand for the base air fare and the 49-passenger augmentor wing STOL airplane are shown in table 5-9.

5.5 ECONOMIC COMPARISONS

With the results of the network model for each aircraft in its respective time period, the concepts can now be compared on a total economic basis. Figure 5-15 shows the daily cash operating costs, sinking funds, interest on investment, and revenue for the three passenger capacities of the two 1975 concepts flown in the 1980 time period. Figure 5-16 displays the same information for the 1985 aircraft flown in the 1990 time period.

Several interesting relationships can be observed from these figures. Although the operating costs for the 1975 helicopter are higher than the augmentor wing STOL, its much reduced terminal investment reduces the loss by 34%. This same effect is shown for the 1985 aircraft in 1990. The slower block speed of the helicopter causes it to carry fewer passengers than the STOL where the VTOLports and STOLports are located at the same place. Where the VTOLports are closer to the passenger demand, this speed difference is more than made up. The 50-passenger helicopter system in 1980 carries 8% more passengers than the STOL system. The tilt-rotor VTOL aircraft combines the two favorable effects. It has the high speed of the STOL and operates from the closer-in VTOLports. The result is the most profitable aircraft studied, carrying 36% more passengers in 1990 than the augmentor wing STOL.

For the STOL aircraft in both time periods, the investment cost and sinking funds for aircraft and terminal replacements account for an average of 58% of the total daily costs. The VTOL aircraft reverse this ratio, so that 60% of the total costs are cash operating costs and 40% investment and sinking fund costs.

In all cases, the smallest aircraft (50 passengers) has the smallest total loss and least loss per passenger. As the capacity increases, the average load factor, frequency of service, and total passengers carried reduce causing the increase in loss per passenger.

As all systems show that cash operating profit is not sufficient to supply the required cash for debt costs and sinking funds, outside sources of cash are needed. Possible sources of funds include local and federal subsidies and grants and income to the intraurban system from concessions and leases. Figures 5-17 through 5-21 show five possible cash flows (A, B, C, D, and E) for the best STOL and best VTOL in each time period;

A All loss is covered by local subsidy.

B Concessions and leases are assumed to pay for 50% of the aviation-oriented terminal investment and sinking funds (in addition to paying for the cost of providing the concession and lease space). All other losses are payed for by local subsidy.

C Same as B except concessions and leases pay 100% of the terminal investment and sinking funds.

D A federal grant is assumed to pay for two-thirds of the total initial investment, as has been proposed for ground mass transit studies. Concessions and leases pay half of the remaining terminal investment costs and half of the terminal sinking fund. Again, local subsidy covers the remaining loss.

E Same as D except the local subsidy is reduced by 50% with this amount being covered by continuing federal matching funds.

The general effect of these postulated subsidies and concession and lease income assumptions is to bring the required local subsidy for the STOL systems down to a level comparable to the helicopter systems. For the tilt-rotor VTOL, the required local subsidy becomes zero for plans C, D, and E. Plan D appears to be the most probable plan and should be used for estimating the impact on the community.

5.6 SENSITIVITY STUDIES

In addition to the base airplane comparisons presented in section 5.5, a number of analyses are made to show the sensitivity of the basic results to the more important parameters of the study.

At this point, a moment of reflection is in order. As the sensitivity studies were made for this report, each new sensitivity uncovered relationships that provided new insight to this totally new problem of using aircraft in an intraurban commuter transportation system. The base systems were adjusted twice in an attempt to keep them near optimal. However, some of the final sensitivities suggest that more optimal combinations exist that would further reduce required subsidies or losses per passenger. Further difficulty is added by the lack of a well-defined criterion of excellence that is applicable to all systems.

To provide some measure of the contribution of the technology advances assumed for the 1985 aircraft, the cash flow comparison of figure 5-22 is presented. It shows the relative cash flows for the 1975 STOL and VTOL operating in the 1990 environment and compares these with the 1985 aircraft in the same environment.

For the augmentor wing STOL aircraft, the advanced technology results in a 13.5% reduction in cash DOCs. This reduces total costs by only 4.5%, but the total loss and, therefore, loss per passenger is reduced by 10%.

The technology advancements for the helicopter result in a 19% reduction in cash DOC per trip with a 24% increase in cruise speed (170 to 210 kn–315 to 389 km/hr). This increased cruise speed attracts 11% more passengers, as reflected in the additional revenue shown. The total cash flow for the 1985 helicopter in the 1990 market is 5% lower than the 1975 helicopter, but the net loss is reduced 39% and this reduced loss, spread over the greater number of passengers carried, results in a 46% lower loss per passenger.

The effect of design field length for the augmentor wing STOL in 1975 is shown in figure 5-23. The general decrease in cash DOC of 19% by increasing field length from 1000 to 3000 ft (305 to 915 m) is overshadowed by the 45% increase in sinking fund and interest costs. The investment in ground facilities increased 57% while the aircraft investment reduced 15%. Including the cost of the STOL terminals in the analysis (as shown) suggests that the 1000-ft (305-m) STOL is best. If cash flow plan D from section 5.5 is used here, the reverse could be shown. Plan D essentially eliminates the effect of the increased STOLport costs as the federal grant and concession income pay for all but one-sixth of their cost.

It can be concluded, however, that for the augmentor wing powered-lift STOL, the total cost of the system can be reduced by designing to as low a field length as 1000 ft (305 m). The loss or subsidy per passenger required at 1000 ft (305 m) is 9% lower than at 2000 ft (610 m).

Figure 5-24 shows the effect on total loss per passenger of flying the STOL aircraft at much slower cruise speeds. The lower cruise speeds increase the cash DOC per trip and decrease the available market. The net effect is a 24% increase in the loss per passenger as the cruise speed is cut from Mach 0.59 to Mach 0.3.

The impact of increased gate time for the augmentor wing STOL is shown in figure 5-25. The basic designs all use the type I interior ("European train") and operate with a 3-min gate time. The type II interior is modified from the type I by joining compartments in pairs and removing every other door. The type III interior is more conventional with four-abreast seating and four doors but still allows a gate time of 5 min if the engines are kept running and the passenger elevators are automated as for the base-case intraurban system. The incremental loss for the conventional interior operated at the same gate time as the type I is only 15 cents per passenger. The major effect on system cost is directly attributed to the unproductive time spent at the gate. This has a twofold effect: first, fleet size must be increased to carry the same number of passengers through the peak periods of the day, and, second, the terminals must be expanded to include the additional gates required. The IOC also increases by the manpower required for the additional gates. The net effect of increasing the gate time for the type I aircraft by 5 min (3 to 8 min) increases the loss per passenger by $1.05 or 26%.

If the price of the augmentor wing STOL were based on a more typical production quantity (300 to 400 versus 1500 to 2000), the price/cost would increase by about 60%. The effect of this increase on the cash flow is illustrated in figure 5-26. The cash DOC is increased 12%, and the total costs are increased 11%. The resultant loss per passenger is increased 21%.

The passenger demand, as a function of time of day, is typical of rush-hour traffic in any large city. The effect of this highly peaked demand is shown in figure 5-27. Data scatter is due to differences in optimality of the schedules produced by the network model for the various degrees of peaking. Eliminating the peaks allows a much smaller fleet of aircraft to carry the same number of people during one day's operation. This allows an increase in daily cash operating profit (revenue minus cash DOC and IOC) of $18 000. Increasing the relative peaking has a decreasing effect primrily because a high percentage of the travelers were already in the peaks in the base case (1.0).

Figure 5-28 illustrates the effect of varying the base fare. The results are a good example of why a scheduling model is necessary to find true sensitivities. The base fare was determined by an analysis outside the network model (sec. 11.3) using a constant load factor.

That analysis showed the base fare to have near-optimal loss per passenger. With the scheduling model calculating the load factor, a different answer is found. As the fare is reduced, each link carries more passengers. The effect of density on a link is to increase the average load factor. As load factor increases, the cost per passenger decreases almost proportionally. In addition, as the demand increases substantially, new links are added to existing terminals further reducing the investment and sinking funds per passenger for that terminal. The net effect is that the loss per passenger is continuing to decrease at the lowest fare shown. Following the incremental trends indicates a minimum loss per passenger of $1.25 at a fare equal to 55% of the base fare.

The effect of eliminating the STOLports in downtown San Francisco is shown in figure 5-29. Eliminating STOLport 1, which is located over the ferry building at the foot of Market Street, reduces the demand by only 2000 passengers and results in a reduction of 23 cents (5%) in the loss per passenger. The passengers usually carried through terminal 1 were carried through terminal 3, and the majority of the cost savings is in the investment and sinking funds for the $88 000 000 terminal at zone 1. As the remainder of the terminals near downtown San Francisco are eliminated, the system loses over 40% of the passengers carried in the base system. The net loss is decreased, but the loss per passenger carried is increased 15%. However, factors not included in the above cash-flow analysis are perhaps more important. Leaving out the three downtown terminals eliminates service to the prime business center for the area, resulting in no reductions in the number of automobiles using the bridges into downtown San Francisco and no relief for congested streets and parking areas in San Francisco.

The primary purpose in including the modal-split function in the systems analysis loop is to show the interaction between system variables and passenger demand. This modal-split function is nothing more than a mathematical model of the decisionmaking process used by the real-world traveler in choosing a mode of travel. The number of factors used by this real-world traveler in choosing a mode is obviously much greater than is used in the simple modal-split model described in section 5.4 (and in much more detail in section 11.1.2). In addition, each traveler uses a different set of factors or at least weighs each factor differently in arriving at his decision.

The relationship used here reduces the decision to one of comparing time and cost for each mode. The effect on demand of varying the intercepts to the modal-split plane is shown in figure 5-30. The most sensitive of the intercepts is ΔC_0, the additional cost of the air mode where penetration goes to zero (at equal trip times).

5.7 BARTD COMPARISON

Although the primary motive for any modern public mass transportation system is to replace all or part of automobile traffice in a given area, it is inevitable (and proper) that the competing methods of mass transit be compared. In the San Francisco area, BARTD is scheduled to begin initial service in the fall of 1971. It seems appropriate, then, to compare the aircraft intraurban system with BARTD, as shown in table 5-10. The data presented here for BARTD comes from references 2 and 3.

The BARTD system is primarily a short-range system, carrying 85% of its passengers less than 16 mi (26 km), while the airplane system carried 83% of its passengers more than 16 mi (26 km). It is estimated that both systems capture about the same number of auto passengers (60 000 versus 50 000), although the automobile road miles saved by the airplane system will be twice that saved by BARTD, due to the much longer average range of the airplane system.

BARTD carries four times the number of passengers carried by the intraurban system. However, in productivity (revenue passenger-miles), BARTD is only 50% higher than the intraurban system. The initial investment for BARTD is 75% to 200% more than the intraurban system resulting in an annual cost to the taxpayers of 100% to 200% more.

The basic system analysis in this study has assumed that no ground rapid transit (BARTD) is available. Figure 5-31 shows the effect on the system economics if the intraurban system must compete with BARTD as it will exist in 1975. The fares for the highly subsidized BARTD system at ranges over 10 mi (16 km) are less than the out-of-pocket expense of operating a car.

The intraurban system cannot compete with BARTD between the same points. When links with direct competition by BARTD are eliminated, the intraurban system carries 45% fewer passengers. The loss per passenger rises to $6.93, an increase of 70%.

5.8 COMMUNITY SUITABILITY

There are many criteria to be considered in judging community acceptability of a new transportation system. In the case of the intraurban system, probably the most critical criterion is community noise. Additional criteria considered are relative safety, pollution, and air traffic control congestion.

Community noise and compatible land use are two of the most important considerations in locating terminals in this study. The assessment of the impact of aircraft noise on the community takes into account the noise level, the frequency of flights, the time of day (whether day or night), and the amount of ambient noise already present in the vicinity of concern.

The system used for describing the reaction of people to noise is the noise exposure forecast (NEF) (ref. 4) modified to include the effects of ambient noise NEF_A. Figures 5-32 through 5-39 show contours of constant NEF_A for the 1975 augmentor wing STOL and helicopter using the frequency of operations from the base 1980 systems. For reference, a 95-EPNdB contour is included in figures 5-32 and 5-33. These contours apply to all port locations as they are not a function of background noise or number of movements.

Noise criteria for an intraurban system should strive for acceptability rather than test the endurance of the people it affects. Robinson's criterion (ref. 5) of 85 PNdB, which he considers the maximum allowable in a quiet residential area, corresponds approximately to a preferred speech interference level (PSIL) of 65 dB, which will permit uninterrupted speech communication over distances of 2 to 8 ft (0.6 to 2.4 m). This is consistent with communication requirements for domestic recreation activities and other pursuits accompanying which conversation is common and desirable. The corresponding NEF_A is, therefore, established as 10 for residential areas and 15 for industrial areas.

The addition of a large number of flights (2000-3000) over a densely populated metropolitan area raises the question of relative safety of the aircraft to other modes of travel. The figures on fatal accidents per million departures for U.S. scheduled air carriers show a continuing improvement with time. For 1969, this number was 1.5 fatal accidents per million departures. Many factors must be used to modify this number for the intraurban system. On the favorable side are time, approach speed, and automation. Unfavorable factors include the ratio of available to required field lenth and air congestion.

It is assumed here that the continuation of accident rate improvement with time, and the reduction of landing accidents resulting from automatic landing equipment will overcome the unfavorable factors mentioned and result in an accident rate for the intraurban system of 0.5 per million departures. This rate for the base system would result in a long-term average of 4.7 passenger fatalities per year. The air system would, however, remove a substantial number of automobiles from the highways which is estimated to save at least a similar number of lives per year. The intraurban system would then contribute no additional fatalities.

The augmentor wing STOL aircraft will emit approximately 2 lb (0.9 kg) of pollutants per 1000 mi (1609 km) per passenger carried. Existing automobiles emit approximately 212 lb (96.1 kg) per 1000 automobile miles (1609 automobile km). If all autos are modified to meet 1972 federal standards, this is reduced to 60, and proposed 1975 federal standards further reduce the number to 20. This is still one order of magnitude above the intraurban system assuming a single occupant per automobile. Further improvements are expected for both the automobile and aircraft by 1985. The augmentor wing STOL emissions should reduce by a factor of three.

The inclusion of 2000 to 3000 additional flights into the Bay area would cause unacceptable congestion and delays if the intraurban aircraft were controlled by the same procedures used for today's tactical IFR movements. The intraurban system must be controlled by one of the possible fourth-generation ATC systems. For this study, a strategically controlled time-synchronized system is assumed. A central ground-based computer would handle all control and scheduling for the fleet, directing their automated flight by a data-link communications system. In addition, for the downtown STOLports of the larger systems studied, an increase in today's runway acceptance rate is required during the morning and evening peak movement periods.

In the 1985 to 1990 time period, the present tactically controlled flights would be merged with the intraurban flights into a single fourth-generation system. In both time periods, the dense intraurban links would use dedicated airspace. This will reduce, somewhat, the amount of free space available for uncontrolled VFR flights but will not eliminate it.

From the factors considered, it would seem that the aircraft system can make a meaningful contribution to the transportation needs of the area without becoming an unwelcome neighbor. This is not to say that the local populace around suggested terminal locations will not object. The airplane in the past has been a rather noisy neighbor, and a large public relations effort will be needed to eliminate this image.

TABLE 5-1.–GENERAL CHARACTERISTICS–50-PASSENGER AIRCRAFT

Airplane components	1975 augmentor wing STOL	1985 augmentor wing STOL	1975 helicopter	1985 helicopter	1985 tilt-rotor VTOL	1975 augmentor wing STOL	1985 augmentor wing STOL	1975 helicopter	1985 helicopter	1985 tilt rotor VTOL	Units
	English units					International system of units					
Wing span, ft	63.6	47.4	–	–	51.1	19.4	14.4			15.6	m
Area, sq ft	675	375	–	–	408	62.7	34.8			37.9	m^2
Aspect ratio	6.0	6.0	–	–	6.43	6.0	6.0			6.43	
t/c, %	21.0	27.0	–	–	21.0	21.0	27.0			21.0	%
Rotor diameter, ft	–	–	56.0	56.0	37.2			17.1	17.1	11.3	m
Disc area, sq ft	–	–	4 926	4 926	2 174			457.6	457.6	202.0	m^2
Number of blades	–	–	4	4	3			4	4	3	
Body length, ft	61.0	61.0	64.0	64.0	62.5	18.6	18.6	19.5	19.5	19.0	m
Diameter, in.	130.5	130.5	120.0	120.0	130.5	3.31	3.31	3.05	3.05	3.31	m
Number of engines	2	2	4	4	4	2	2	4	4	4	
Thrust/power per engine	7 240 lb	6 900 lb	1 844 hp	1 650 hp	1 967	3 284kg	3 130 kg	1 377 kW	1 230 kW	1 468 kW	
OEW, lb	24 160	17 497	27 269	22 737	20 365	10959	7937	12369	10314	9238	kg
Payload, lb	9 800	9 800	10 000	10 000	10 000	4445	4445	4536	4536	4536	kg
Max taxi weight, lb	37 118	29 977	40 289	35 142	32 240	16837	13598	18273	15940	14624	kg
Field length, ft	2 000	2 000	–	–	–	610	610				m
Range, nmi	100	100	100	100	100	185	185	185	185	185	km
Cruise speed, kn	325	325	172	214	302	602	602	319	396	559	km/hr
Wing loading, lb/ft^2	55.0	80.0	–	–	79.1	268	391			386	kg/m^2
Thrust loading, lb/lb or HP/lb	0.39	0.46	0.183	0.188	0.244	0.39	0.46	.301	.310	.402	kg/kg or w/g
Payload/GW	0.264	0.327	0.248	0.285	0.310	0.264	0.327	0.248	0.285	0.310	

TABLE 5-2.–GENERAL CHARACTERISTICS–100-PASSENGER AIRCRAFT

Airplane components	1975 augmentor wing STOL	1985 augmentor wing STOL	1975 helicopter	1985 helicopter	1985 tilt-rotor VTOL	1975 augmentor wing STOL	1985 augmentor wing STOL	1975 helicopter	1985 helicopter	1985 tilt rotor VTOL	Units
	English units					International system of units					
Wing span, ft	81.1	60.4	–	–	67.0	24.7	18.4	–	–	20.4	m
Area, sq ft	1 097	607	–	–	758	101.9	56.4	–	–	70.4	m^2
Aspect ratio	6.0	6.0	–	–	5.92	6.0	6.0	–	–	5.92	–
t/c, %	21.0	27.0	–	–	21.0	21.0	27.0	–	–	21.0	%
Rotor diameter, ft	–	–	75.75	75.75	50.7	–	–	23.1	23.1	15.5	m
Disc area, sq ft	–	–	9 012	9 012	4 037	–	–	837.2	837.2	375.0	m^2
Number of blades	–	–	4	4	3	–	–	4	4	3	–
Body length, ft	86.0	86.0	82.5	82.5	88.7	26.2	26.2	25.1	25.1	27.0	m
Diameter, in.	145.0	145.0	160.0	160.0	145.0	3.68	3.68	4.06	4.06	3.68	m
Number of engines	2	2	4	4	4	2	2	4	4	4	–
Thrust/power per engine	11 770 lb	11 170 lb	3 380 HP	3 075 HP	3 670 HP	5 339 kg	5 067 kg	2 520 kW	2 295 kW	2 740 kW	–
OEW, lb	36 408	25 393	48 226	40 604	36 699	16 515	11 518	21 875	18 418	16 647	kg
Payload, lb	19 000	19 000	19 600	19 600	20 000	8 618	8 618	8 891	8 891	9 072	kg
Max taxi weight, lb	60 350	48 580	73 756	65 074	60 039	27 375	22 036	33 456	29 518	27 233	kg
Field length, ft	2 000	2 000	–	–	–	610	610	–	–	–	m
Range, nmi	100	100	100	100	100	185	185	185	185	185	km
Cruise speed, kn	325	325	172	214	320	602	602	318	396	593	km/hr
Wing loading, lb/ft^2	55.0	80.0	–	–	79.3	268	391	–	–	387	kg/m^2
Thrust loading, lb/lb or HP/lb	0.39	0.46	0.184	0.189	0.244	0.39	0.46	.303	.311	.402	kg/kg or W/g
Payload/GW	0.315	0.391	0.266	0.301	0.333	0.315	0.391	0.266	0.301	0.333	

TABLE 5-3.–WEIGHT SUMMARY–50-PASSENGER AIRCRAFT

Airplane components	1975 augmentor wing STOL	1985 augmentor wing STOL	1975 helicopter	1985 helicopter	1985 tilt-rotor VTOL	1975 augmentor wing STOL	1985 augmentor wing STOL	1975 helicopter	1985 helicopter	1985 tilt-rotor VTOL
	lb					kg				
Wing	4 126	1 573	–	–	2 111	1 872	714	–	–	958
Horizontal tail	625	311	–	–	437	283	141	–	–	198
Vertical tail	377	202	–	–		171	92	–	–	
Body	6 678	4 741	6 435	4 440	3 374	3 029	2 150	2 919	2 014	1 530
Landing gear	933	828	1 315	1 155	1 141	423	376	596	524	518
Nacelle and strut	418	508	725	552	549	190	230	329	250	249
Rotor	–	–	3 873	3 719	–	–	–	1 757	1 687	–
Total structure	13 156	8 164	12 348	9 866	7 612	5 968	3 703	5 601	4 475	3 453
Engine	1 857	1 694	940	738	894	842	768	426	335	406
Engine accessories	188	185	295	208	318	85	84	134	94	144
Engine systems	357	355	483	371	85	162	161	219	168	38
Thrust reverser	130	161	–	–	–	59	73	–	–	–
Air ducting system	514	383	–	–	–	233	174	–	–	–
Drive system	–	–	4 027	3 656	1 715	–	–	1 827	1 658	778
Propeller installation	–	–	–	–	2 168	–	–	–	–	983
Total propulsion group	3 046	2 778	5 745	4 973	5 180	1 382	1 260	2 606	2 256	2 350
Instruments	424	336	265	211	210	192	152	120	96	95
Surface controls	625	496	1 973	1 948	2 683	284	225	895	884	1 217
Hydraulics	300	213	245	184	185	136	97	111	83	84
Pneumatics	138	117	–	–	–	63	53	–	–	–
Electrical	1 087	761	775	543	545	493	345	352	246	247
Electronics	691	432	750	490	490	313	196	340	222	222
Flight provisions	468	375	220	176	175	212	170	100	80	79
Passenger accommodations	2 706	2 385	2 275	2 025	2 025	1 227	1 082	1 032	918	918
Misc accommodations	95	95	1 198	926	–	43	43	543	420	
Emergency equipment	81	70	135	135	135	37	32	61	61	61
Air conditioning	364	325	750	680	520	165	147	340	308	236
Anti-icing	108	96	70	60	85	49	44	32	27	39
Auxiliary power unit	0	0	0	0	0	0	0	0	0	0
Community noise abatement	354	337	–	–	–	161	153	–	–	
Total fixed equipment	7 441	6 038	8 656	7 378	7 053	3 375	2 739	3 926	3 347	3 199
Exterior paint	0	0	0	0	0	0	0	0	0	0
Options	0	0	0	0	0	0	0	0	0	0
Manufacturer's empty weight	23 643	16 980	26 749	22 217	19 845	10 724	7 702	12 133	10 078	9 002
Standard and operational items	517	517	520	520	520	235	235	236	236	236
Operational empty weight	24 160	17 497	27 269	22 737	20 365	10 959	7 937	12 369	10 314	9 238
Maximum zero fuel weight	33 960	27 927	37 269	32 737	30 365	15 404	12 668	16 905	14 850	13 774
Maximum taxi weight	37 188	29 977	41 000	35 650	32 597	16 837	13 598	18 598	16 171	14 786

TABLE 5-4.–WEIGHT SUMMARY–100-PASSENGER AIRCRAFT

Airplane components	1975 augmentor wing STOL	1985 augmentor wing STOL	1975 helicopter	1985 helicopter	1985 tilt rotor VTOL	1975 augmentor wing STOL	1985 augmentor wing STOL	1975 helicopter	1985 helicopter	1985 tilt-rotor VTOL
	lb					kg				
Wing	7 142	2 514			4 105	3 240	1 140			1 862
Horizontal tail	927	449			875	420	204			397
Vertical tail	559	292				254	132			
Body	10 213	6 922	10 080	6 970	6 323	4 633	3 140	4 572	3 162	2 868
Landing gear	1 400	1 241	2 335	2 065	2 122	635	563	1 059	937	963
Nacelle and strut	780	924	1 267	980	918	354	419	575	445	416
Rotor			7 484	7 252				3 395	3 290	
Total structure	21 022	12 342	21 166	17 267	14 343	9 536	5 598	9 601	7 832	6 506
Engine	3 507	2 964	1 944	1 562	1 496	1 591	1 344	882	709	679
Engine accessories	220	217	546	372	532	100	98	248	168	241
Engine systems	467	464	661	492	151	212	210	300	223	68
Thrust reverser	257	320				117	145		-	
Air ducting system	655	488				297	221		-	-
Drive system			8 353	7 785	3 621			3 789	3 531	1 642
Propeller installation					4 264					1 934
Total propulsion group	5 107	4 452	11 504	10 211	10 064	2 307	2 019	5 218	4 631	4 565
Instruments	436	344	265	211	210	198	156	120	96	95
Surface controls	891	754	3 328	3 344	4 893	404	342	1 509	1 517	2 219
Hydraulics	348	243	265	199	200	158	110	120	90	91
Pneumatics	203	171				92	78			-
Electrical	1 087	761	875	612	615	493	345	397	278	279
Electronics	775	476	750	490	490	352	216	340	222	222
Flight provisions	501	401	220	176	175	227	182	100	80	79
Passenger accommodations	3 974	3 498	4 500	4 000	4 000	1 803	1 587	2 041	1 814	1 814
Misc accommodations	179	179	3 128	2 026		81	81	1 419	919	-
Emergency equipment	118	99	135	135	135	54	45	61	61	61
Air conditioning	477	429	1 500	1 353	970	216	195	680	614	440
Anti-icing	116	100	70	60	85	53	45	32	27	39
Auxiliary power unit	0	0	0	0	0	0	0	0	0	0
Community noise abatement	575	546				261	248			
Total fixed equipment	9 681	8 000	15 036	12 606	11 773	4 391	3 629	6 820	5 718	5 340
Exterior paint	0	0	0	0	0	0	0	0	0	0
Options	0	0	0	0	0	0	0	0	0	0
Manufacturer's empty weight	35 810	24 794	47 706	40 084	36 180	16 243	11 247	21 639	18 182	16 411
Standard and operational items	599	599	520	520	520	272	272	236	236	236
Operational empty weight	36 408	25 393	48 226	40 604	36 700	16 515	11 518	21 875	18 418	16 647
Maximum zero fuel weight	55 408	44 393	67 826	60 204	56 700	25 133	20 137	30 766	27 309	25 719
Maximum taxi weight	60 350	48 580	75 000	66 000	60 636	27 375	22 036	34 020	29 938	27 504

TABLE 5-5.—AIRCRAFT ACQUISITION COSTS

Aircraft type	Passenger capacity	1975 technology, 1970 dollars in millions			1985 technology, 1970 dollars in millions		
		Airframe[a]	Engines	Total	Airframe[a]	Engines	Total
Augmentor wing STOL	49	1.121	0.438	1.559	1.140	0.430	1.570
	95	1.423	0.545	1.968	1.432	0.531	1.963
	153	1.787	0.685	2.472	1.783	0.663	2.446
Helicopter VTOL	50	1.449	0.228	1.677	1.449	0.211	1.660
	98	1.992	0.355	2.347	1.992	0.331	2.323
	150	2.440	0.452	2.892	2.440	0.441	2.881
Tilt rotor VTOL	50			-	1.323	0.239	2.481
	100			–	1.946	0.377	2.323
	150			–	2.481	0.488	2.969

[a] Includes S305 000 for electronics in all cases

TABLE 5-6.—IOC COEFFICIENT SUMMARY

Cost category	Parameter						
	Nodes	Departures, millions	Gates	Miles, millions	Fleet size	(Seats) (dep), millions	Seat miles, millions
Total aircraft servicing cost (TASC)	0.058705		0.097842		0.002446		
Traffic servicing cost (TTSC)	0.042020		0.001013 + (0.00004052) (seats)				
Servicing and administration cost (TSAC)	0.015255		0.013868		0.000347		
General and administration cost (TGAC)	0.0286		0.026		0.00065		
Ground facility cost (TGFC)		1.717		0.0151		0.0233	0.0000792
Passenger liability expense (PLE)						(0.125)LF	
Totals	0.144580	1.717	0.138723 + (0.00004052) (seats)	0.0151	0.003443	0.0233 + (0.125)LF	0.0000792

IOC = 0.14458 (nodes) + 1.717 (departures) + 0.0151 (miles flown)
+ 0.138723 (gates) + 0.00004052 (gates)(seats) + 0.003443 (fleet)
+ 0.0233 (departures)(seats) + 0.125 (departures)(seats)(LF)
+ 0.0000792 (seats)(miles flown)
Millions of dollars per year

TABLE 5-7.—IOC COMPARISON TABLE

Class of service[a]	Passengers, millions	Departures, millions	RPM, billions	IOC, millions	IOC unit costs		
					S/pass	S/dep	S RPM
Domestic	116.671	3.142	90.393	2417.535	20.72	769.0	0.0267
Local	23.388	1.594	6.473	266.835	11.41	167.0	0.0412
Helicopter	0.418	0.064	0.011	4.4	10.52	69.0	0.4000
Intraurban	15.245	0.688	0.356	14.941	0.95	21.0	0.0420

[a]Data for the STOL network is from the base case Data for domestic, local, and helicopter service is from 1969 CAB handbook.

TABLE 5-8.—1980 AIR TERMINAL COST SUMMARY

STOLport				VTOLports			
Zone no.	Terminal type	No. of gates	Cost[b]	Zone no.	Terminal type	No. of gates	Cost[b]
1	C	7	87.9	1	F	6	35.0
2	A	2	37.6	2	F	2	15.7
3	C	3	81.0	3	F	3	19.0
4	B	1	34.3	4	F	2	15.0
5	B	1	34.3	5	G	3	12.6
6	A	3	15.2	6	E	2	7.5
7	A	3	14.4	7	E	2	7.4
8	B	1	14.6	8	E	1	6.2
9	A	2	12.8	9	E	2	7.3
10	-	–	–	10	E	1	6.2
11	A	2	14.6	11	+	2	7.3
12	A	1	11.2	12	E	1	6.1
13	-	–	–	13	E	1	6.2
14	B	2	15.9	14	E	2	7.4
15	A	3	17.0	15	E	3	9.0
16	B	2	27.9	16	F	3	17.4
17	B	2	29.2	16	E	2	9.0
18	B	1	19.3	17	E	1	6.9
20	A	2	13.7	18	E	1	6.4
21	A	1	11.9	20	E	2	7.5
22	B	1	16.7	21	E	1	6.2
24	A	1	12.5	22	E	1	6.3
26	A	1	11.7	24	E	1	6.2
29	A	2	13.7	26	E	1	6.2
30	B	2	24.2	29	E	1	6.3
		Total	609.1	30	E	2	8.0
						Total	255.3

[a]49-passenger airplane

[b]1980 costs in 1970 dollars in millions

TABLE 5-9.—BASE CASE CHARACTERISTICS

Daily passenger demand	60 105	
Daily passengers carried	48 551	
Daily revenue passenger statute miles (kilometers)	1 135 690	(1 827 320)
Daily revenue flights	2 190	
Daily ferry flights	102	
Total daily flights	2 292	
Average load factor	0.447	
Average passenger trip distance (statute miles)(kilometers)	23.4	(37.6)
Aircraft required	73	
Average utilization (hrs/day)	4.22	
Number of gates	48	
Number of terminals	24	
Number of links	65	
Daily DOC (no depreciation)	$114 250	
Daily IOC	$47 586	
Daily TOC	$161 836	
Daily revenue	$174 890	
Daily operating profit	$13 054	

TABLE 5-10.—BARTD COMPARISON

System characteristics	BARTD 1975 estimate	Intraurban 1980 market	
		STOL	Helicopter
Passengers (daily)	200 000	48 551	52 483
Route system, miles (kilometers)	75 (121)	1550 (2494)	1550 (2494)
Stations/ports	33	24	24
Links	528	65	65
Daily revenue passenger miles (kilometers)	1 760 000 (2 830 000)	1 140 000 (1 830 000)	1 105 000 (1 780 000)
Average trip length, miles (kilometers)	9 14.5	23 37	21 34
Initial investment	$1 300 000 000	745 000 000	412 000 000
Annual revenue	$25 000 000	55 000 000	59 000 000
Annual cost to taxpayer	$100 000 000	48 000 000	35 000 000
Average fare	$0.45	$3.60	$3.56
Loss/passenger	$1.70	$4.05	$2.42
Total cost per passenger	$2.15	$7.65	$5.98
Total cost per passenger mile	$0.24	$0.29	$0.27

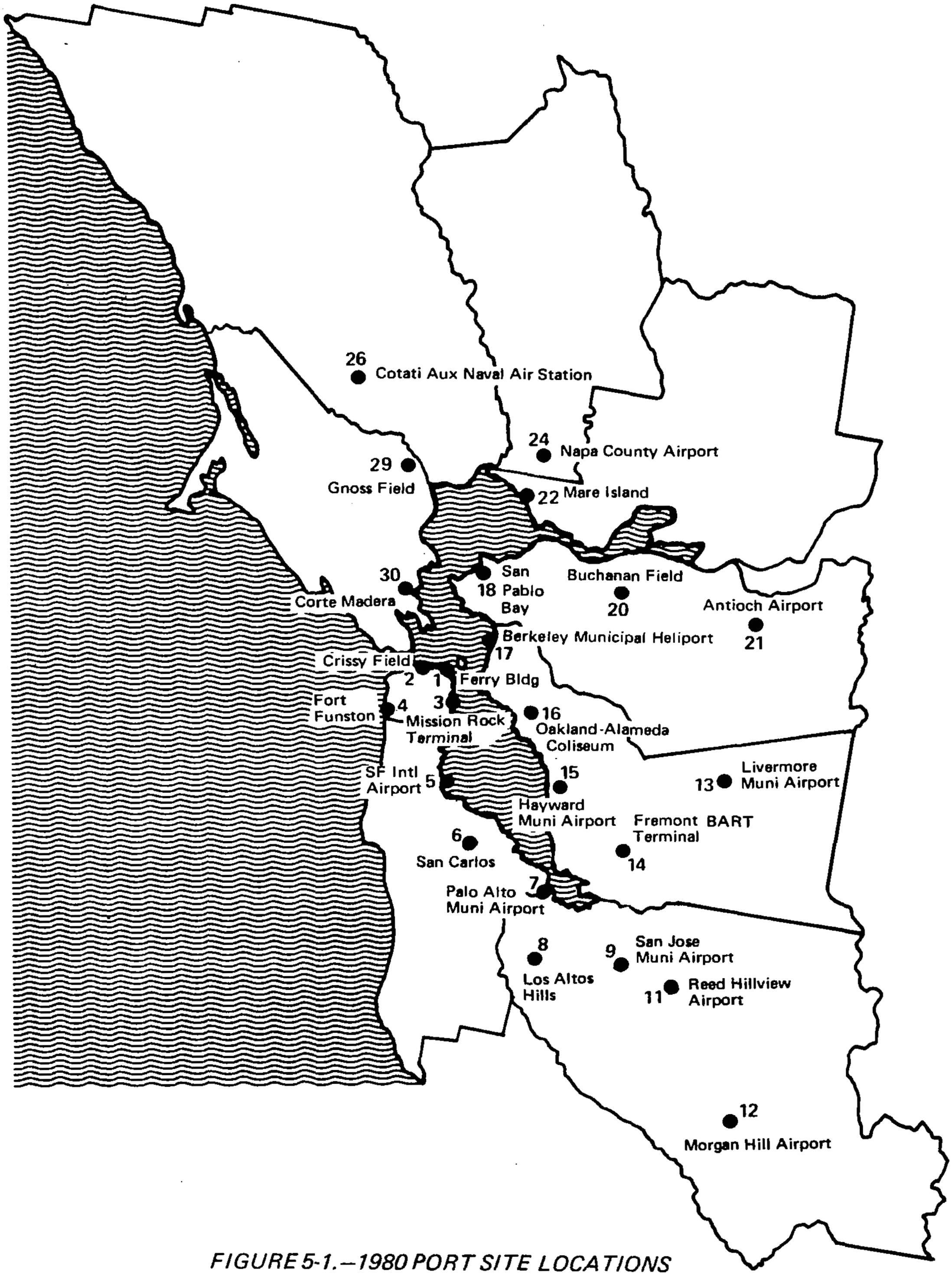


FIGURE 5-1.—1980 PORT SITE LOCATIONS

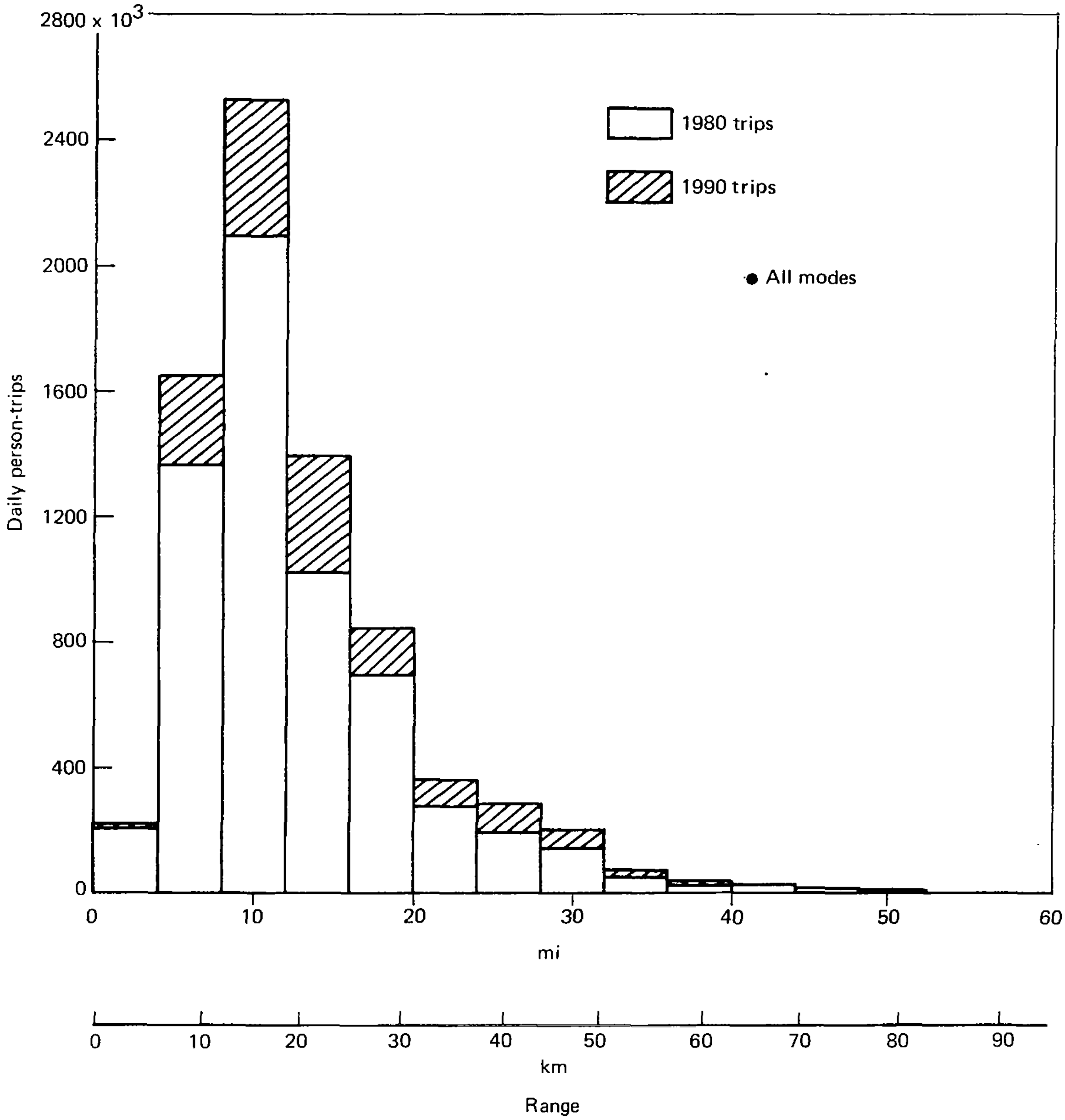


FIGURE 5-2.—TOTAL DAILY PERSON-TRIPS BETWEEN TERMINAL AREAS

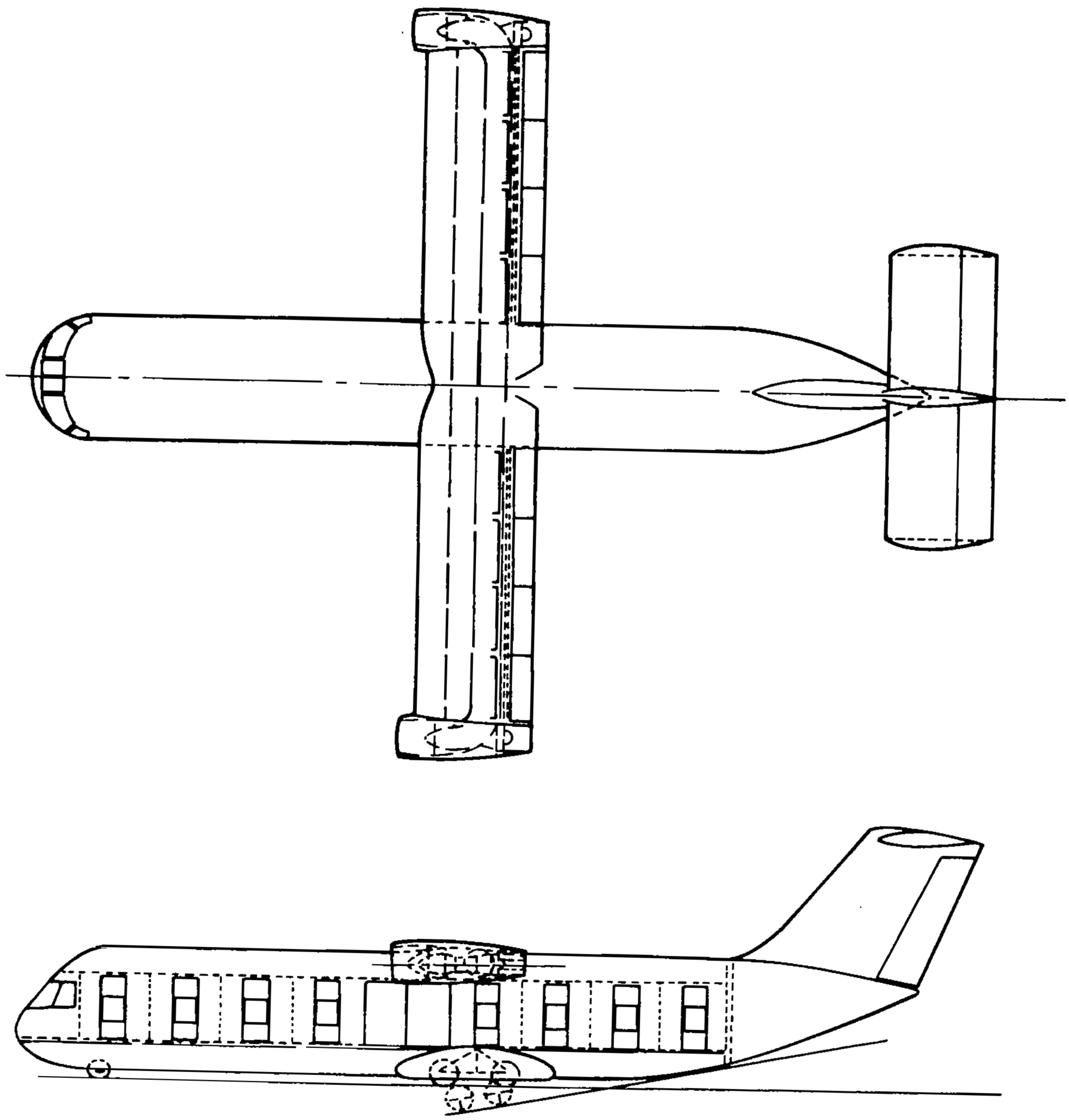


FIGURE 5-3.—1975 AUGMENTOR WING STOL GENERAL ARRANGEMENT, 95 PASSENGERS

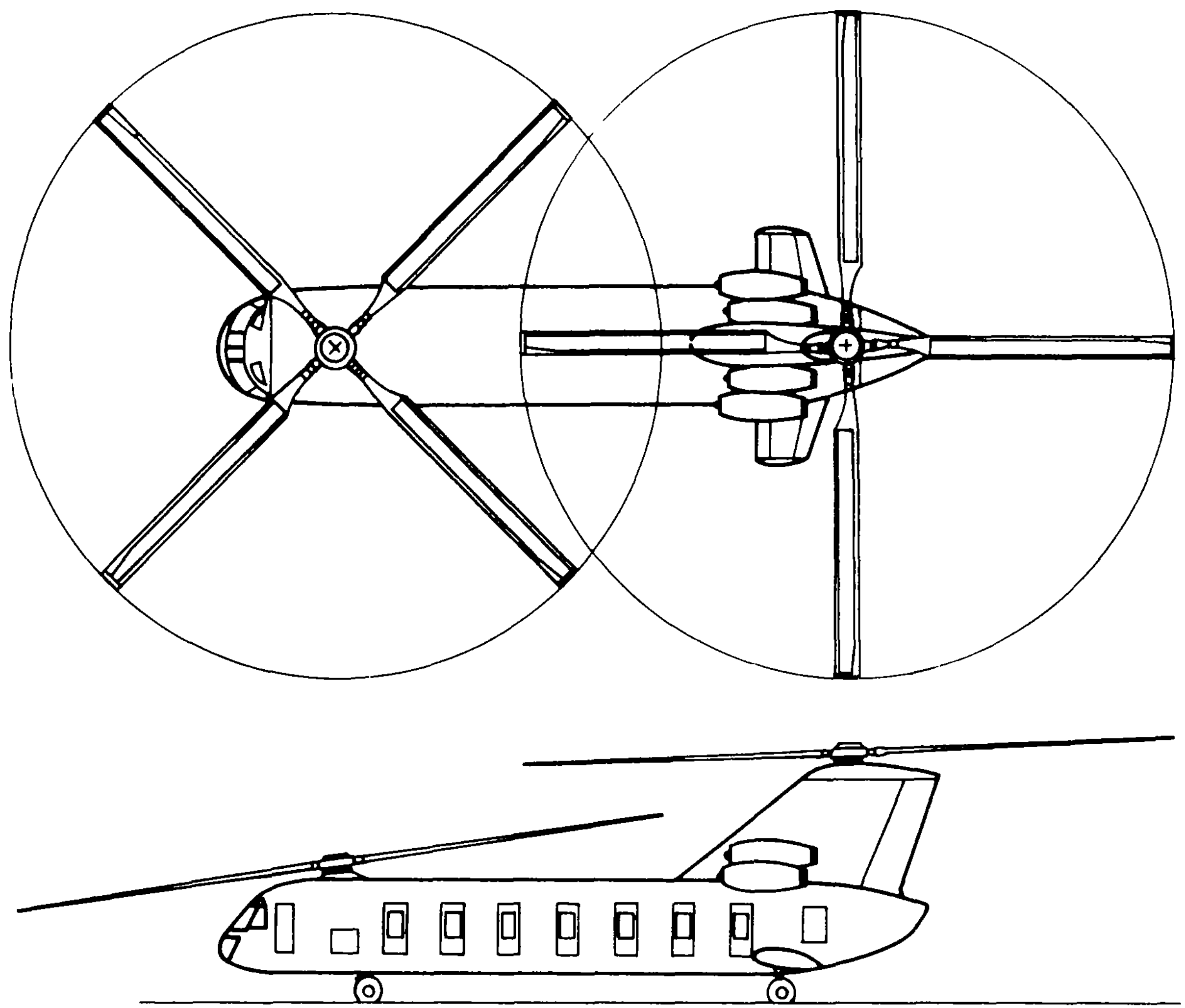


FIGURE 5-4.—1975 HELICOPTER GENERAL ARRANGEMENT—98 PASSENGERS

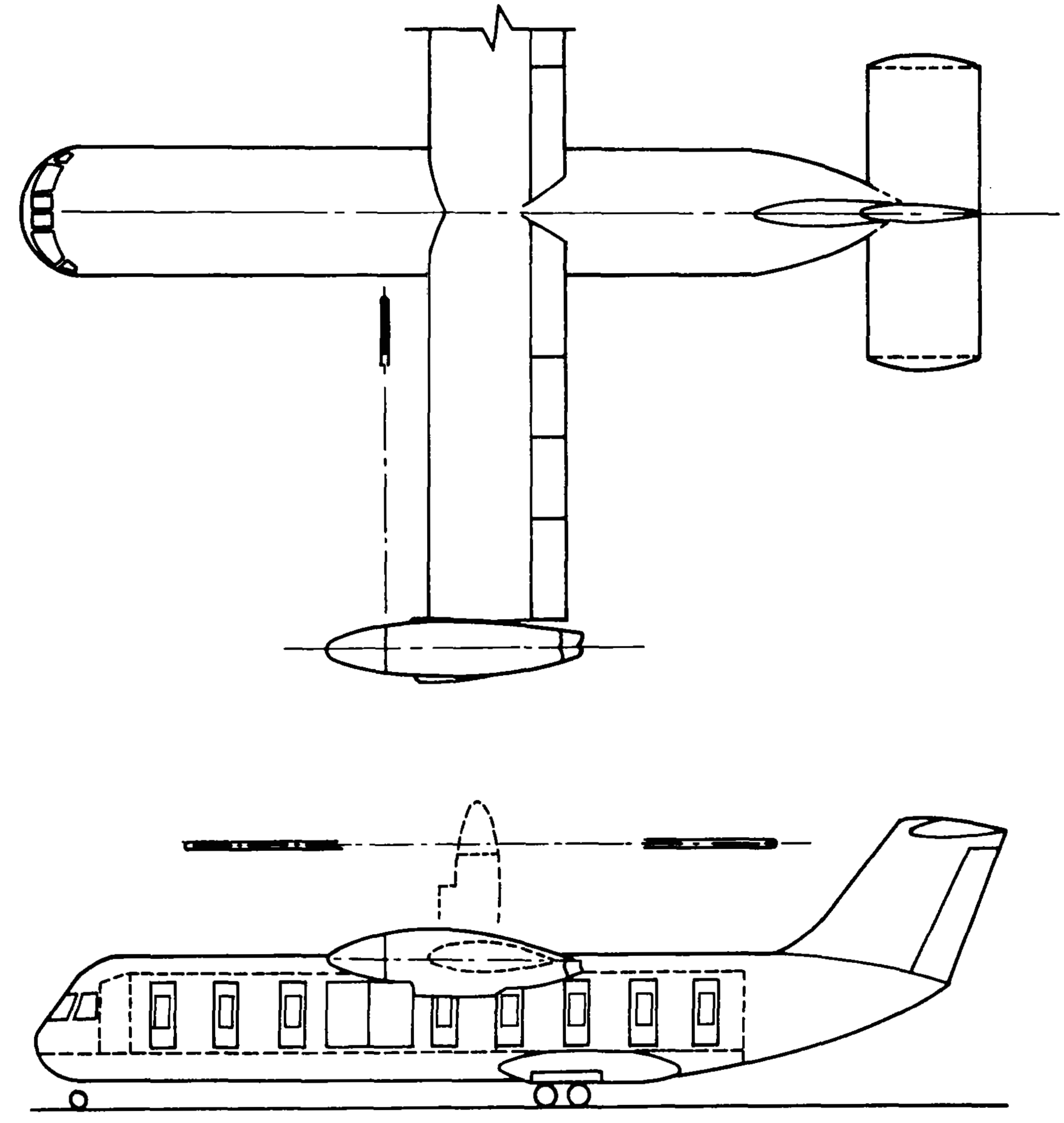


FIGURE 5-5.–1985 TILT ROTOR GENERAL ARRANGEMENT, 100 PASSENGERS

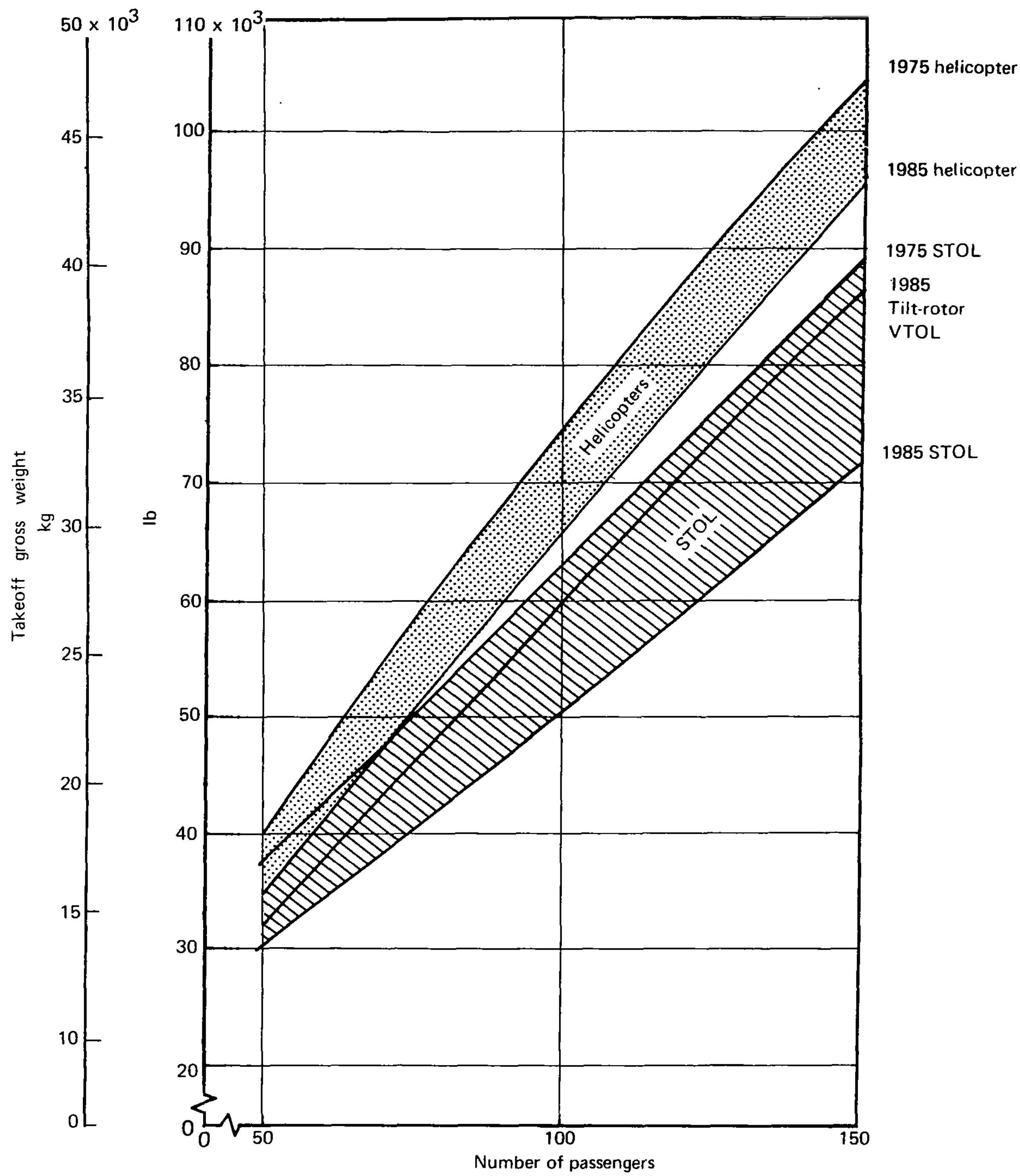


FIGURE 5-6.–TAKEOFF GROSS WEIGHT–BASELINE AIRCRAFT

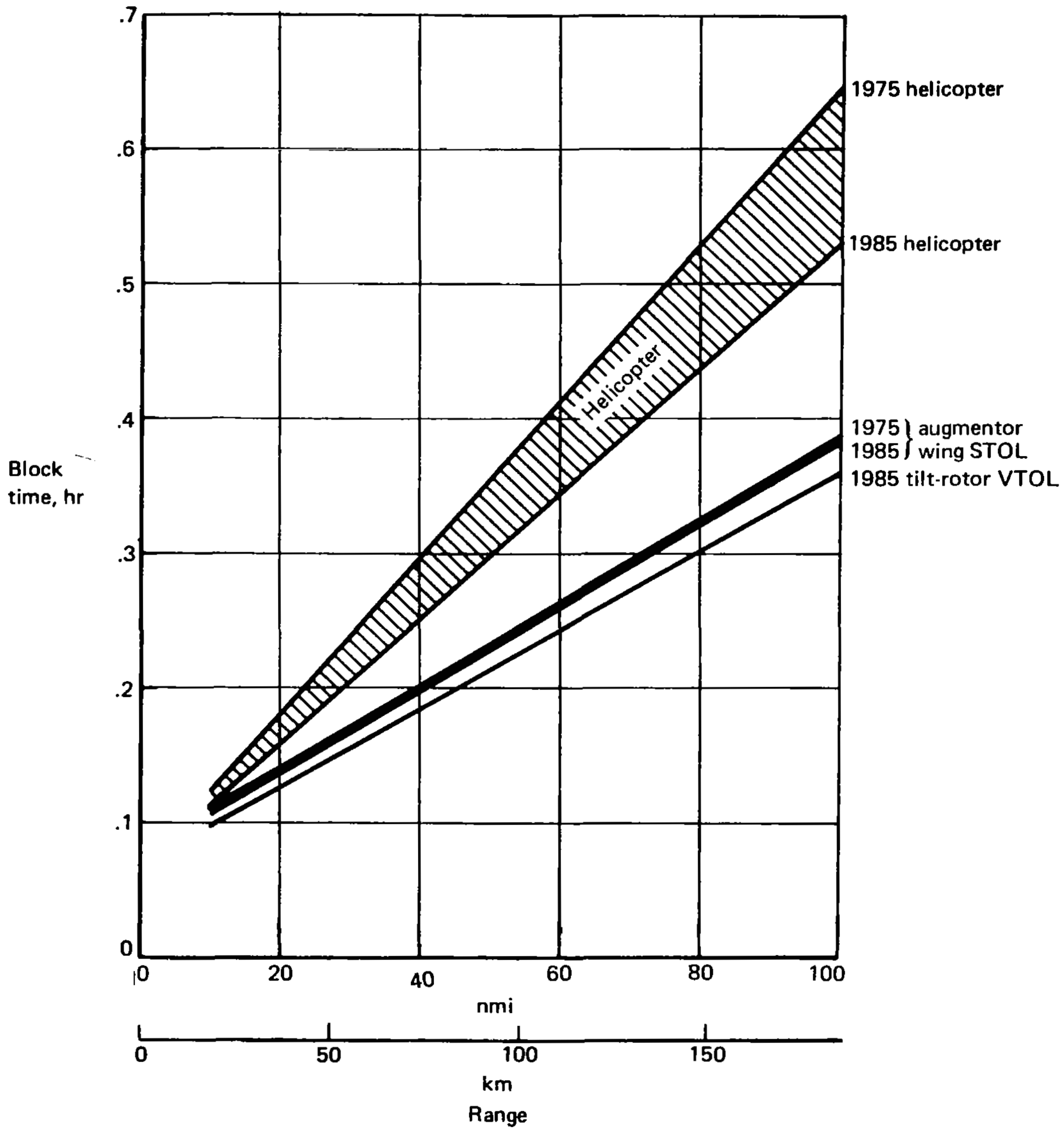


FIGURE 5-7.—BLOCK TIME FOR BASELINE AIRPLANES—100 PASSENGERS

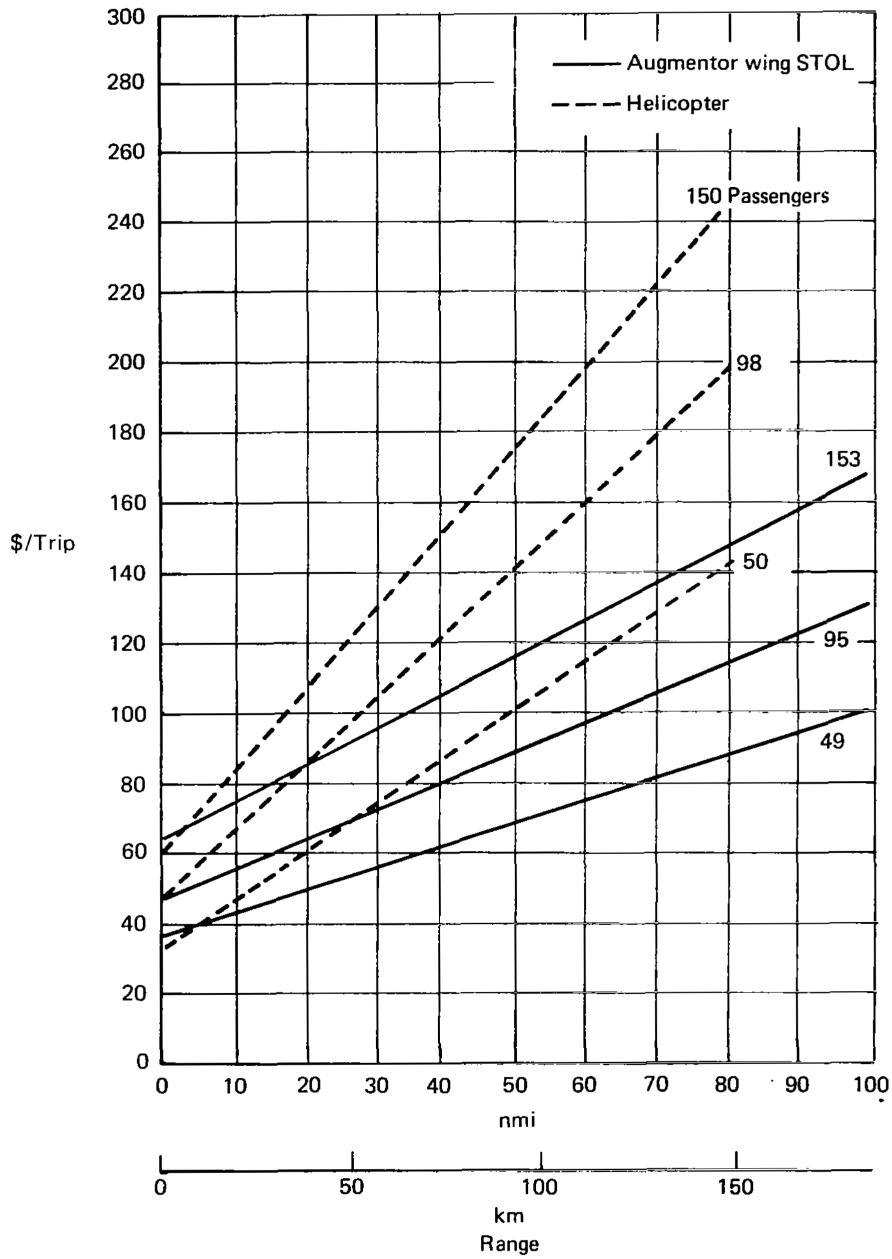


FIGURE 5-8.—CASH DIRECT OPERATING COST MINUS DEPRECIATION (1975)

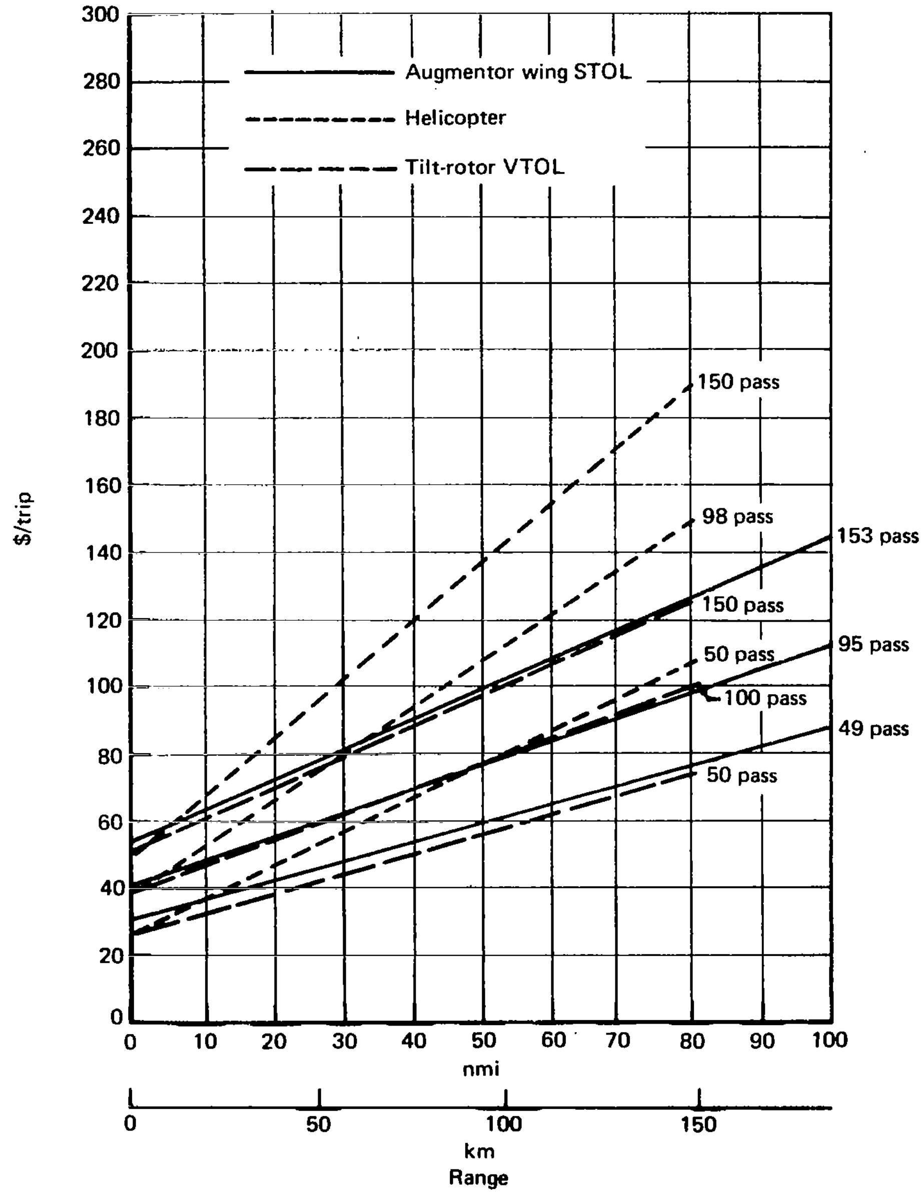


FIGURE 5-9.—CASH DIRECT OPERATING COST MINUS DEPRECIATION (1985)

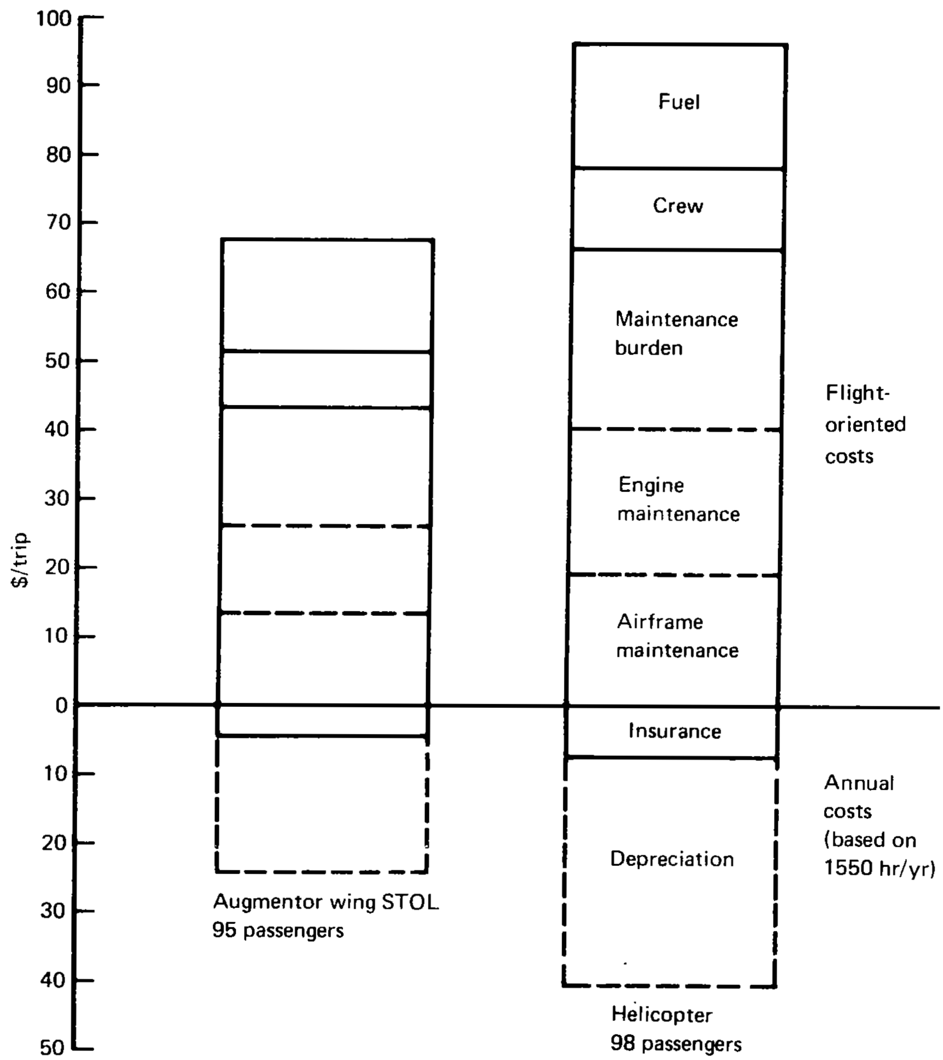


FIGURE 5-10.–CASH DIRECT OPERATING COST PLUS DEPRECIATION—30-NMI (55.5 KM) TRIP (1975)

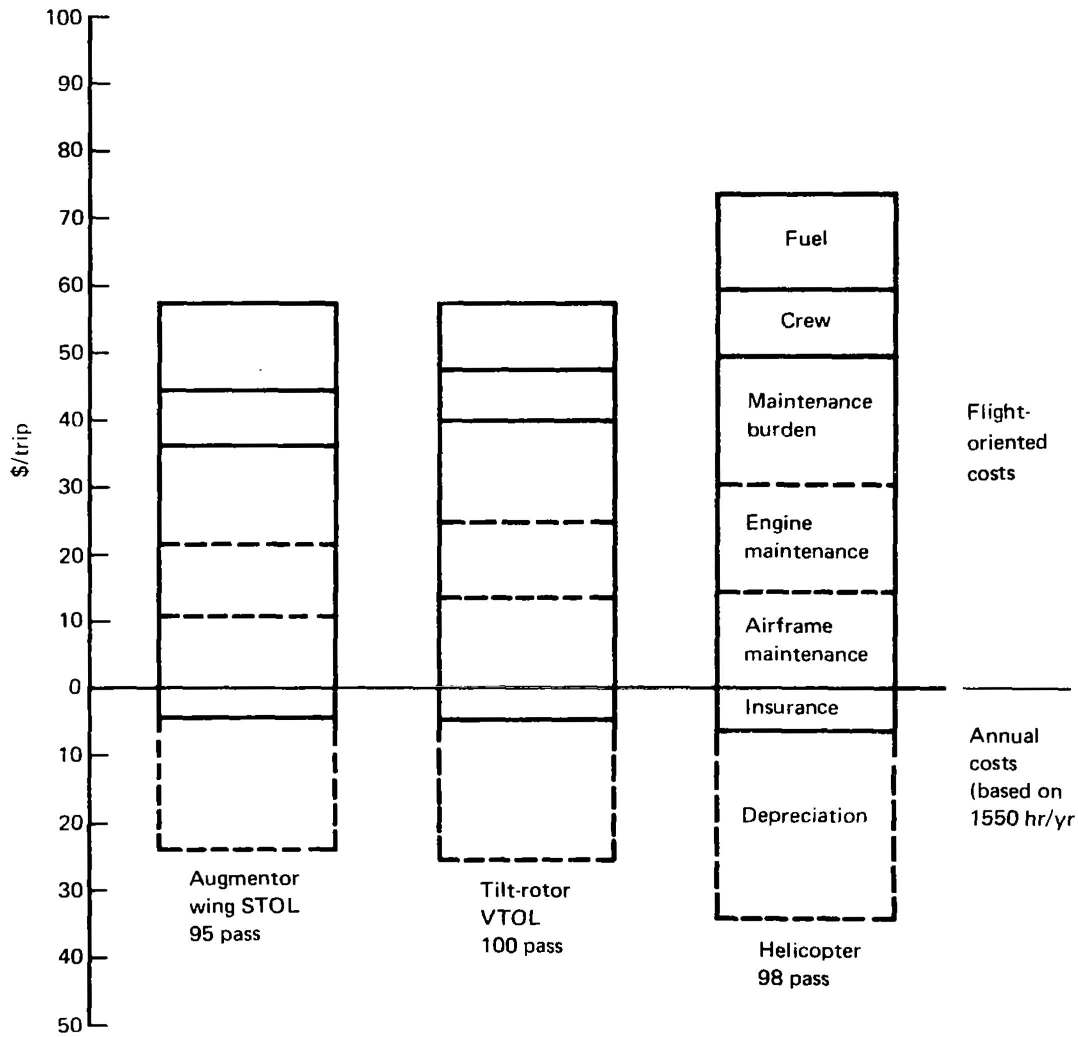


FIGURE 5-11.—CASH DIRECT OPERATING COST PLUS DEPRECIATION—30-NMI (55.5 KM) TRIP (1985)

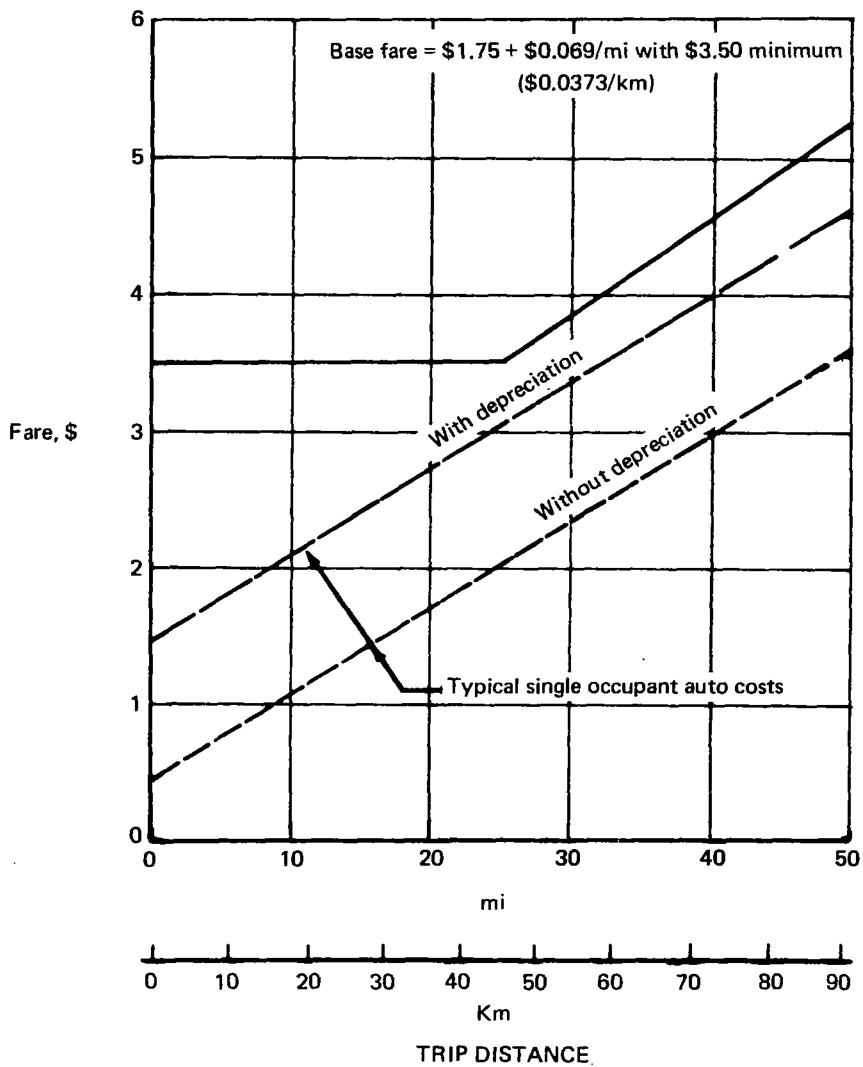


FIGURE 5-12.–BASE FARE LEVEL

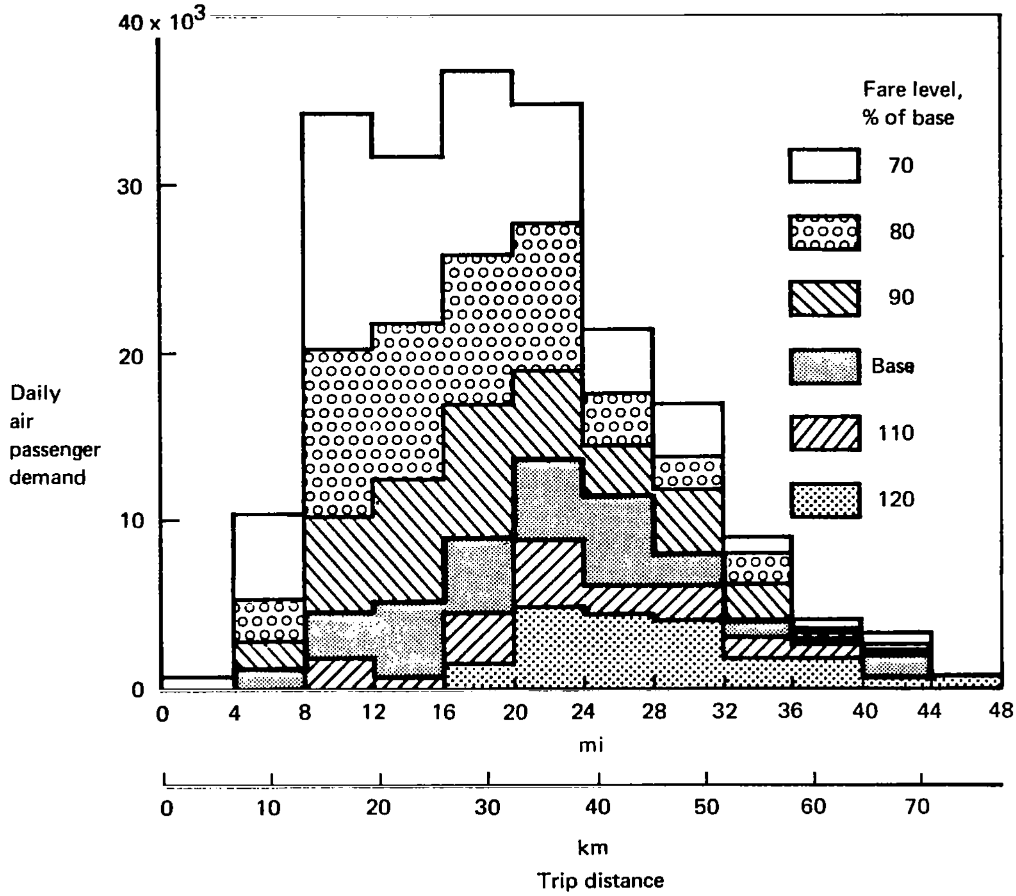


FIGURE 5-13.—TRAVEL DEMAND SENSITIVITY TO FARE 1975 STOL, 1980 MARKET

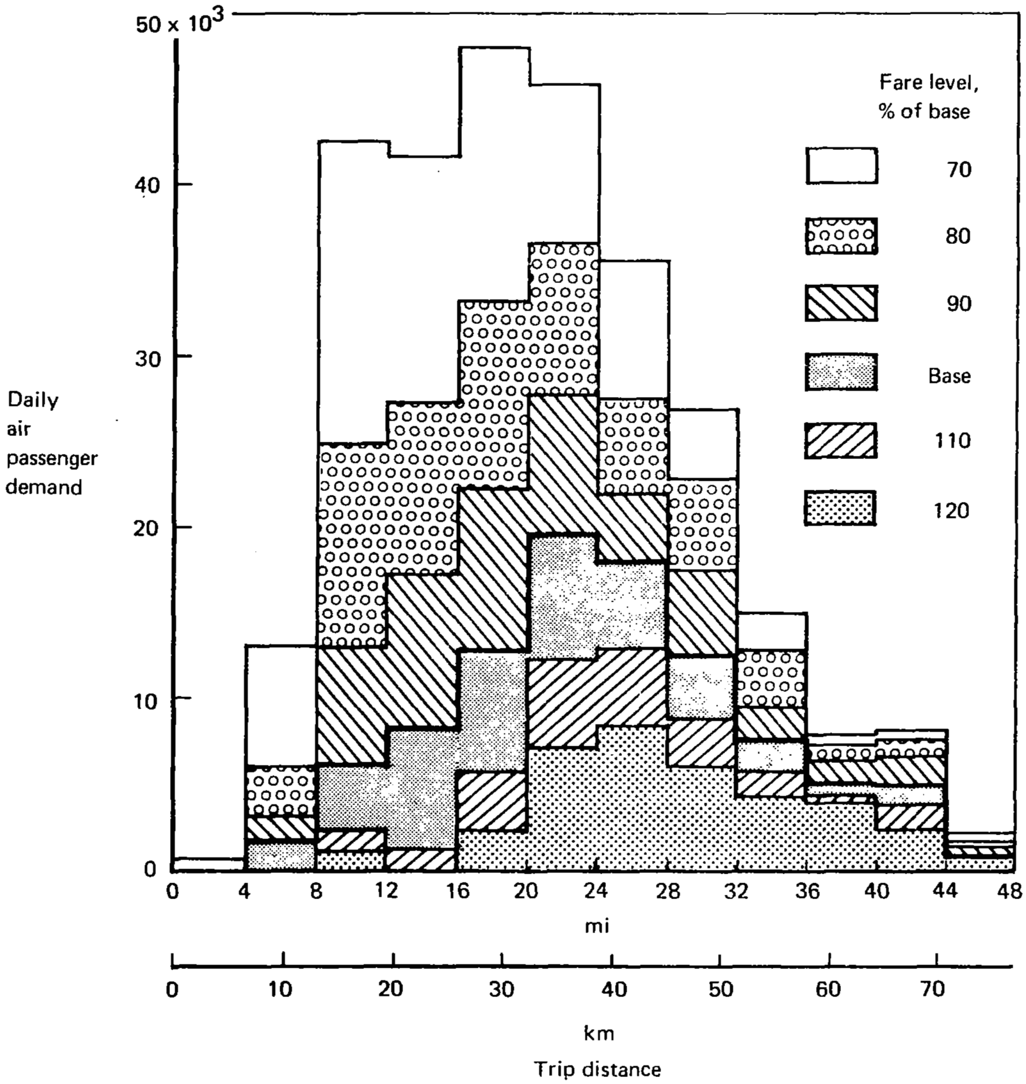
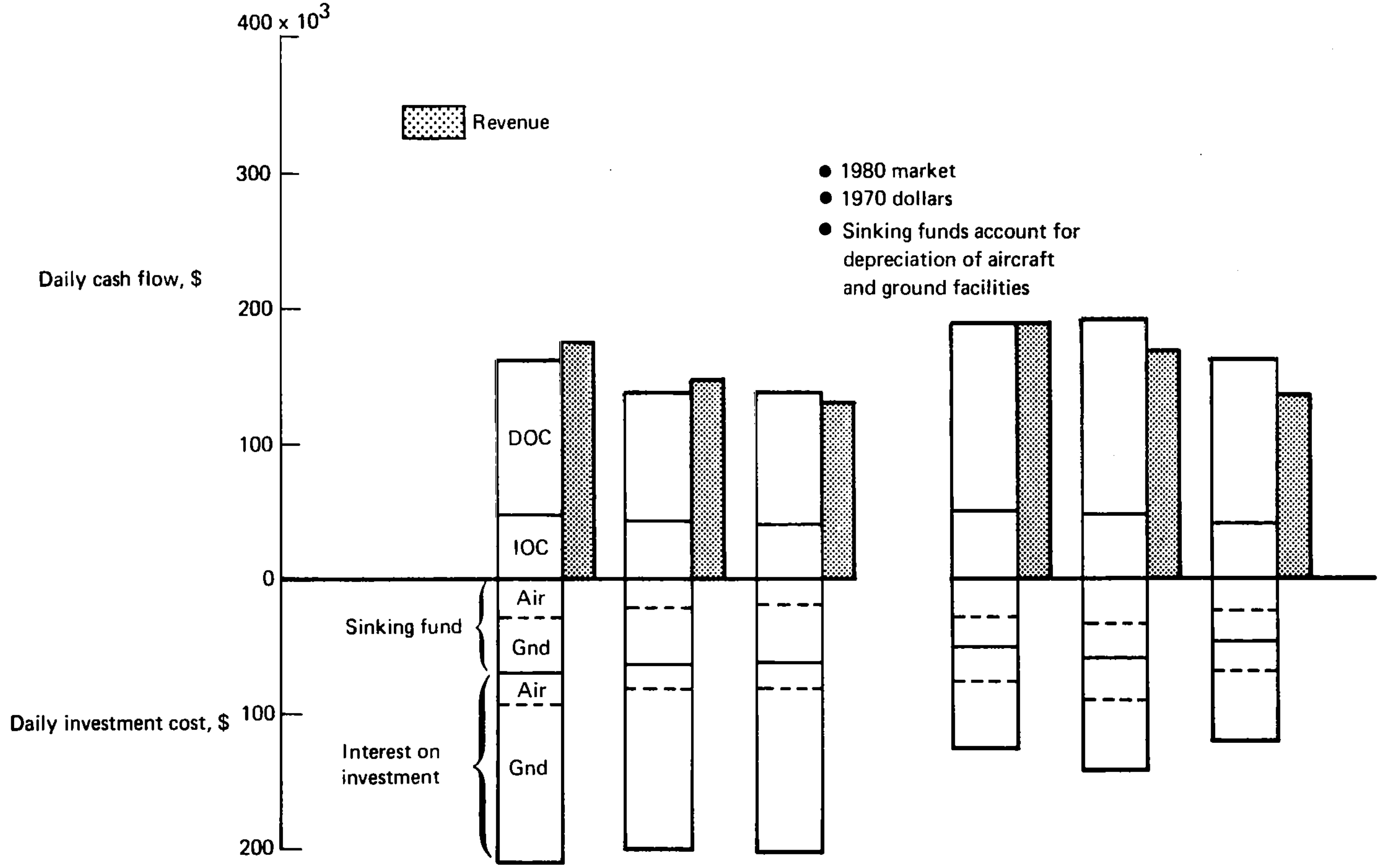
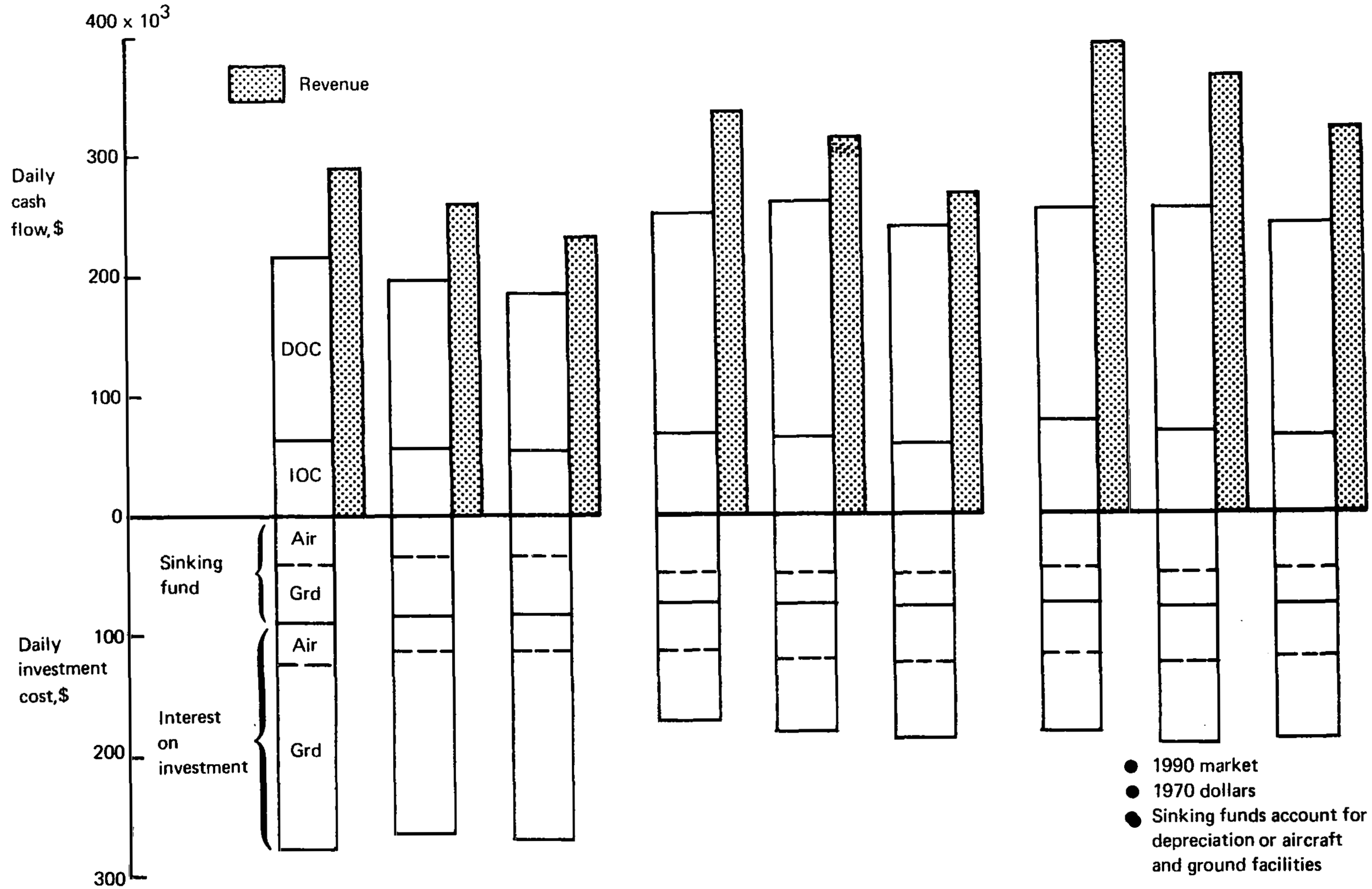


FIGURE 5-14.—TRAVEL DEMAND SENSITIVITY TO FARE
1985 STOL, 1990 MARKET



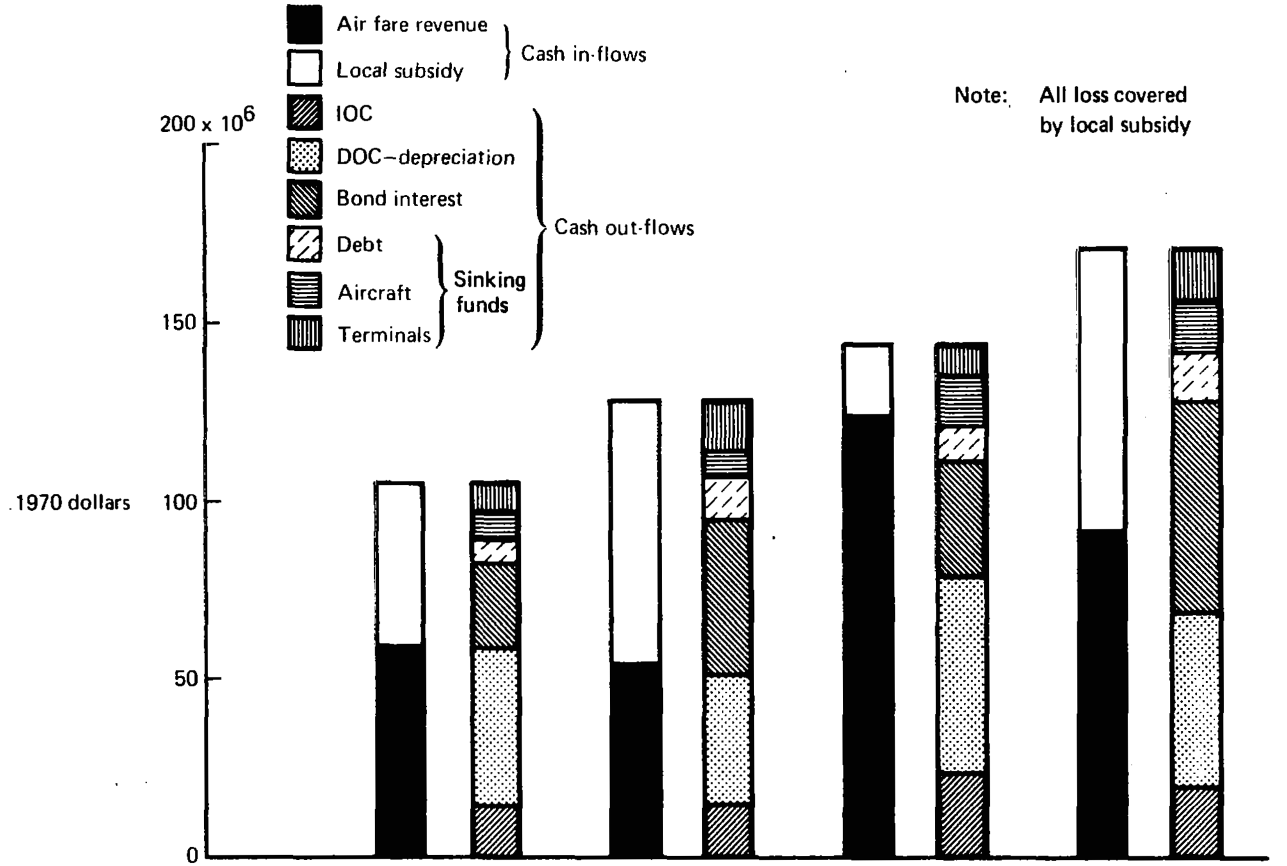
Vehicle	Augmentor wing STOL			Helicopter		
Passengers	49	95	153	50	98	150
Net loss per day	\$194 000	\$190 000	\$208 000	\$128 000	\$163 000	\$147 000
Loss per passenger	\$4.05	\$4.70	\$5.80	\$2.42	\$3.55	\$3.85

FIGURE 5-15.–CONCEPT ECONOMIC COMPARISON–1975 AIRCRAFT



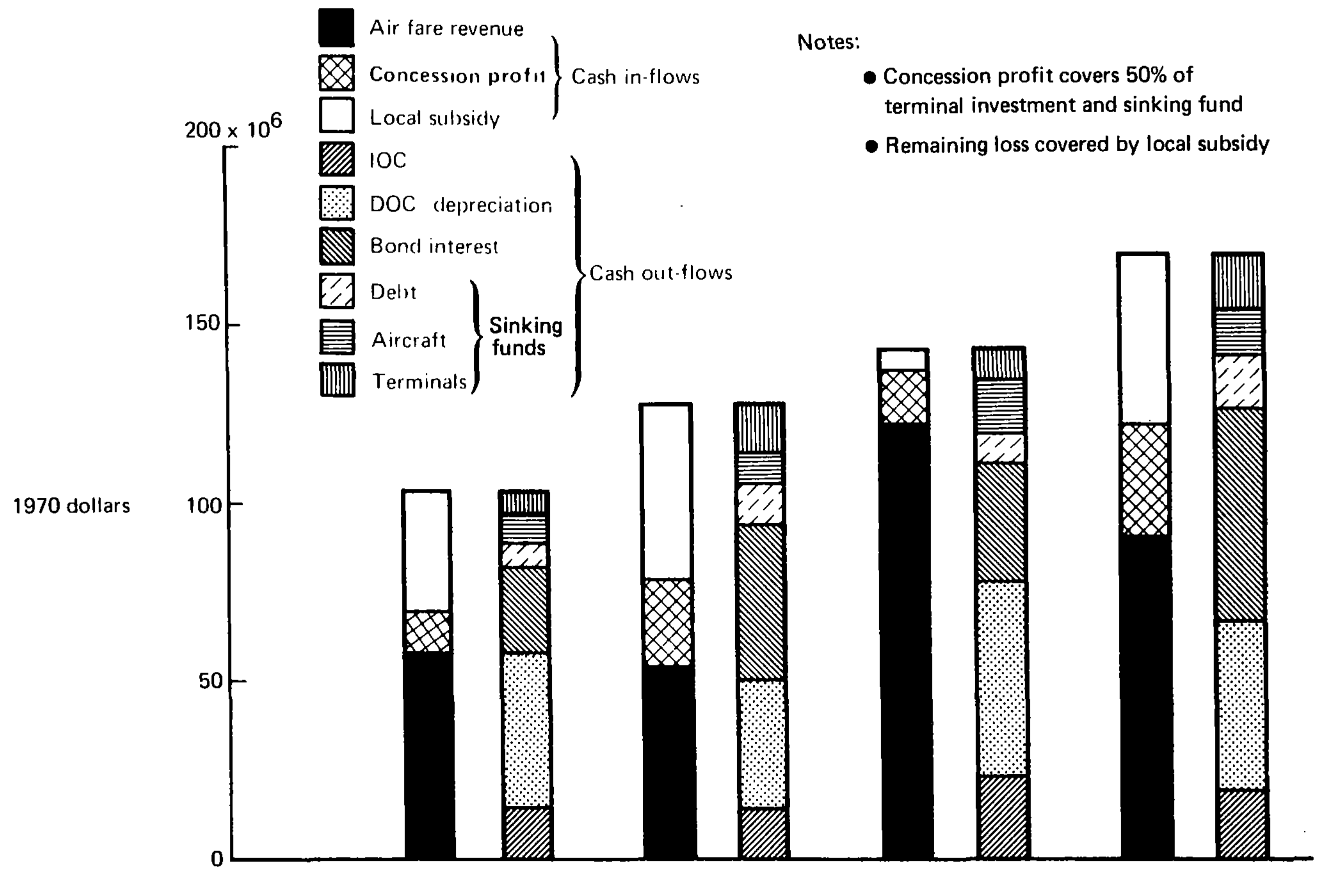
Vehicle	STOL-augmentor			VTOL-helicopter			VTOL-tilt rotor		
Passengers	49	95	153	50	98	150	50	100	150
Loss per passenger	$2.65	$3.00	$3.35	$1.05	$1.35	$1.95	$.40	$.80	$1.25

FIGURE 5-16.—CONCEPT ECONOMIC COMPARISON—1985 AIRCRAFT



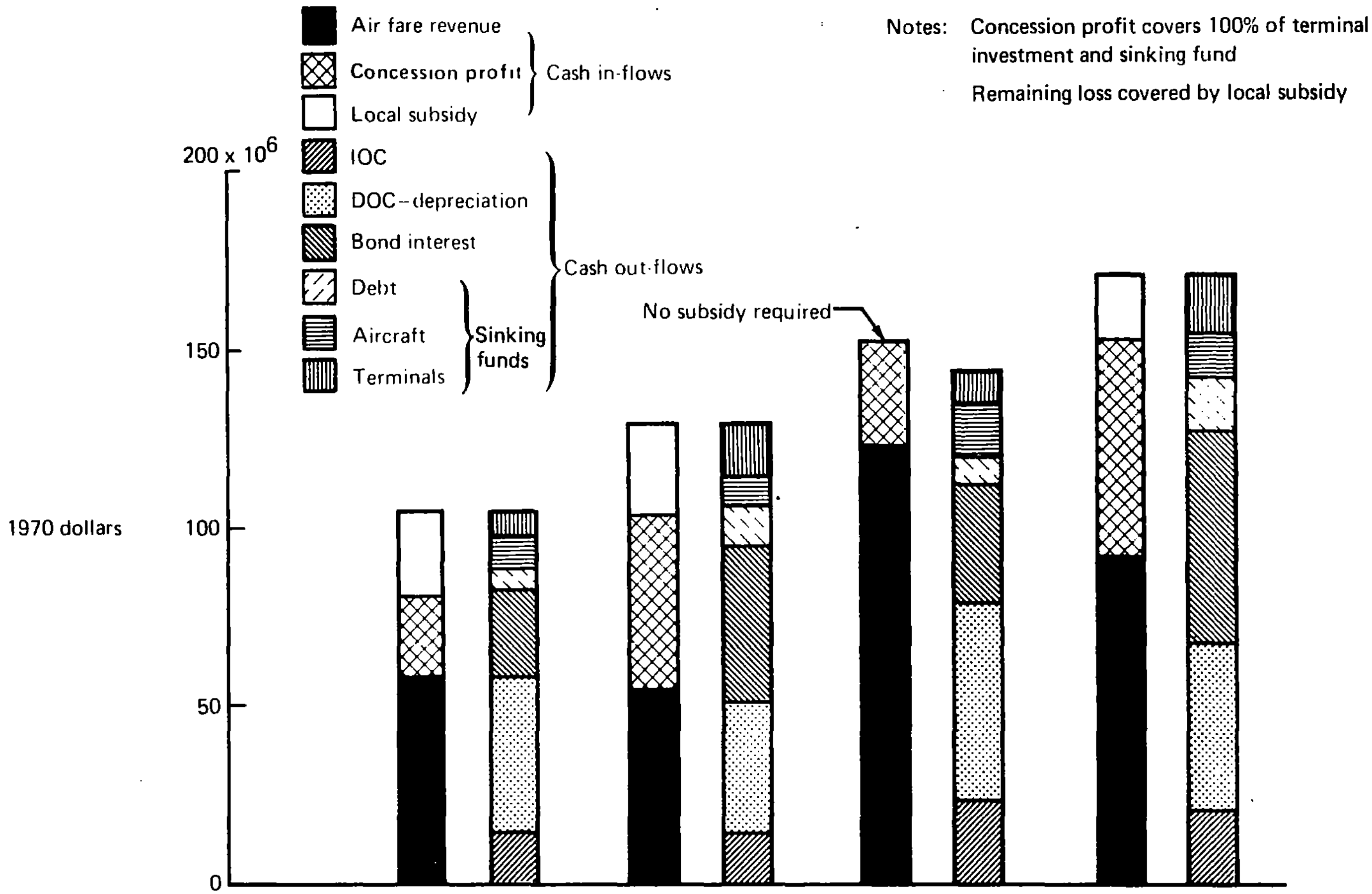
Vehicle	Helicopter	Augmentor wing STOL	Tilt-rotor VTOL	Augmentor wing STOL
Passengers	50	49	50	49
Technology	1975		1985	
Market	1980		1990	

FIGURE 5-17.—ANNUAL CASH FLOW A



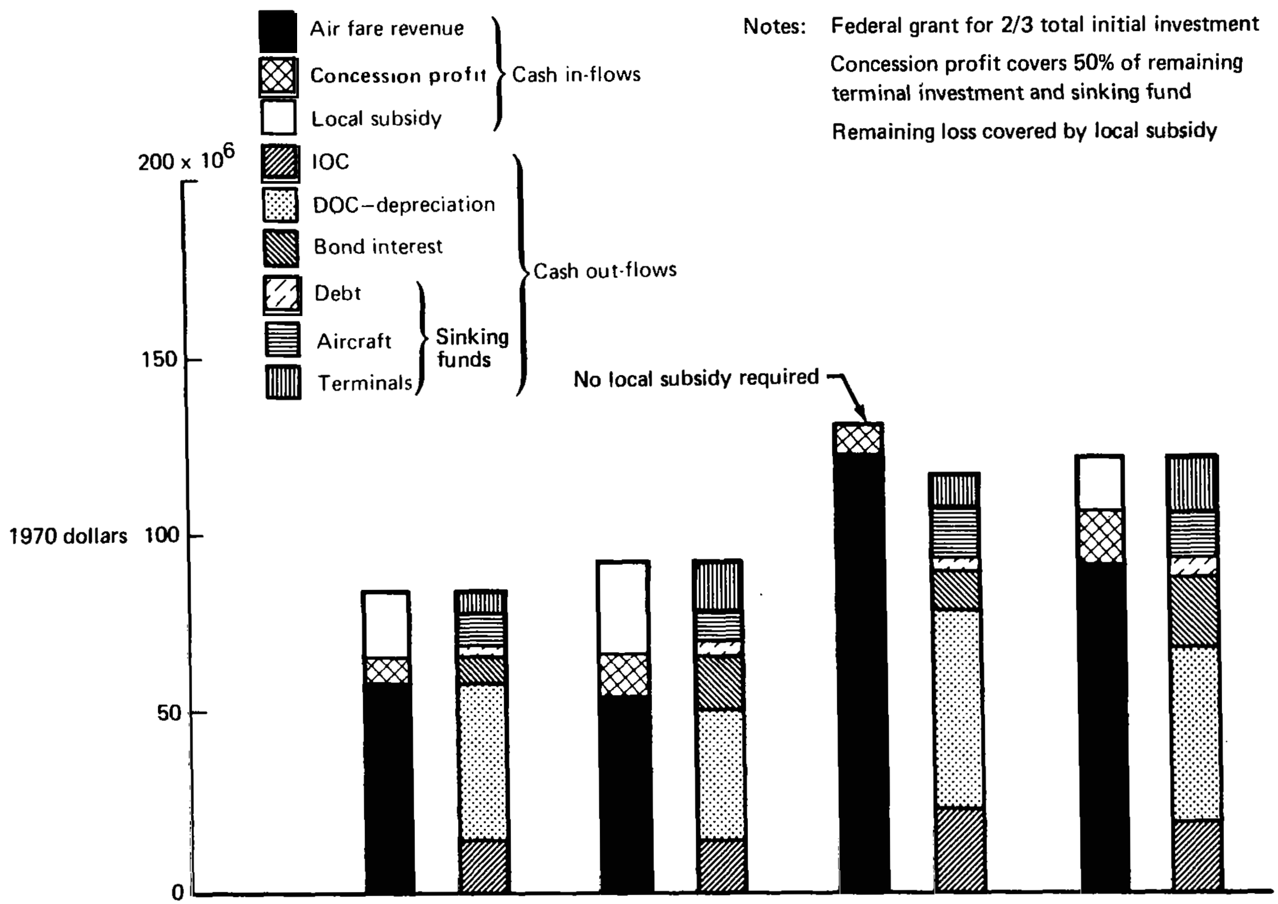
Vehicle	Helicopter	Augmentor wing STOL	Tilt-rotor VTOL	Augmentor wing STOL
Passengers	50	49	50	49
Technology	1975		1985	
Market	1980		1990	

FIGURE 5-18.—ANNUAL CASH FLOW B



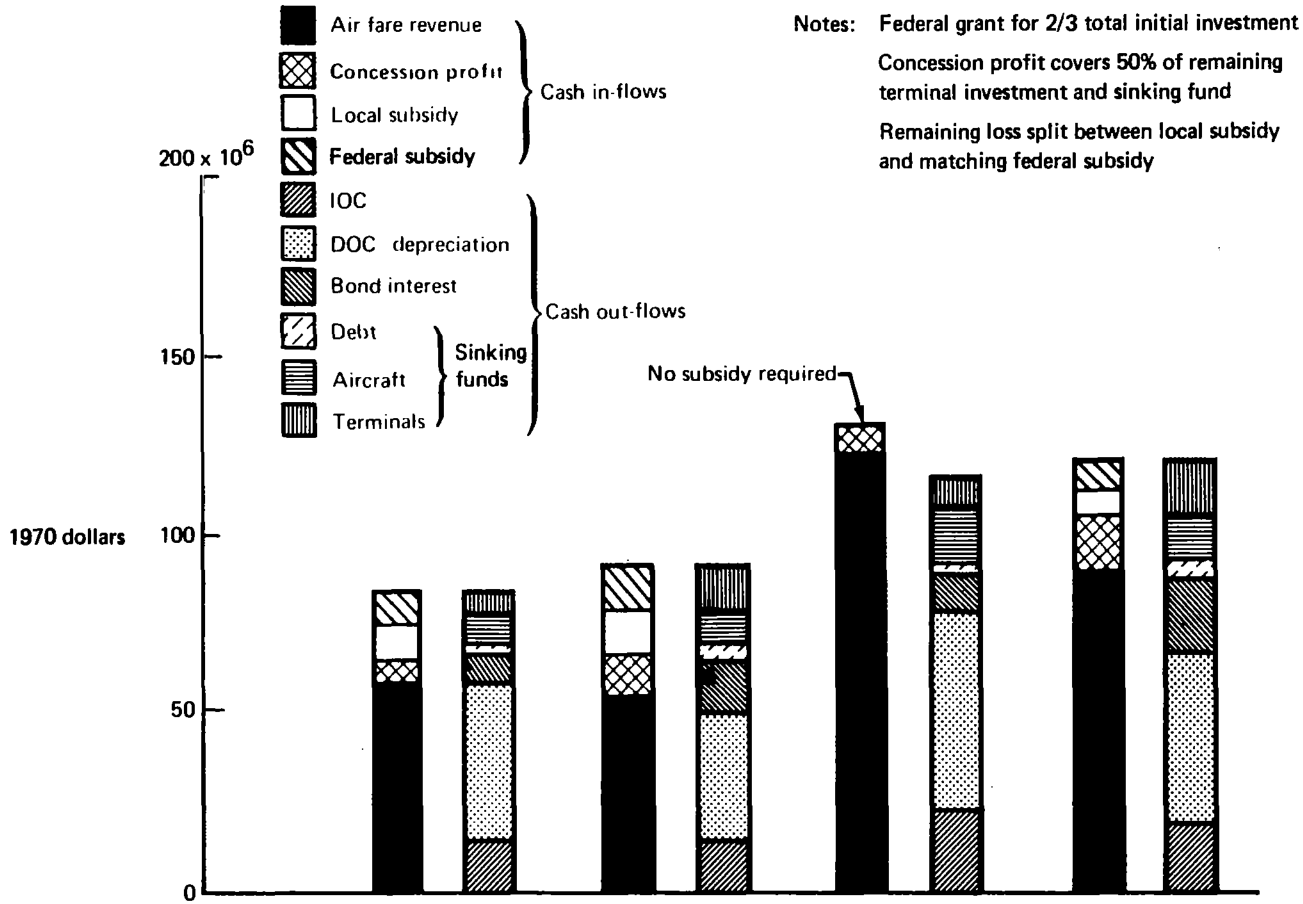
Vehicle	Helicopter	Augmentor wing STOL	Tilt-rotor VTOL	Augmentor wing STOL
Passengers	50	49	50	49
Technology	1975		1985	
Market	1980		1990	

FIGURE 5-19.—ANNUAL CASH FLOW C



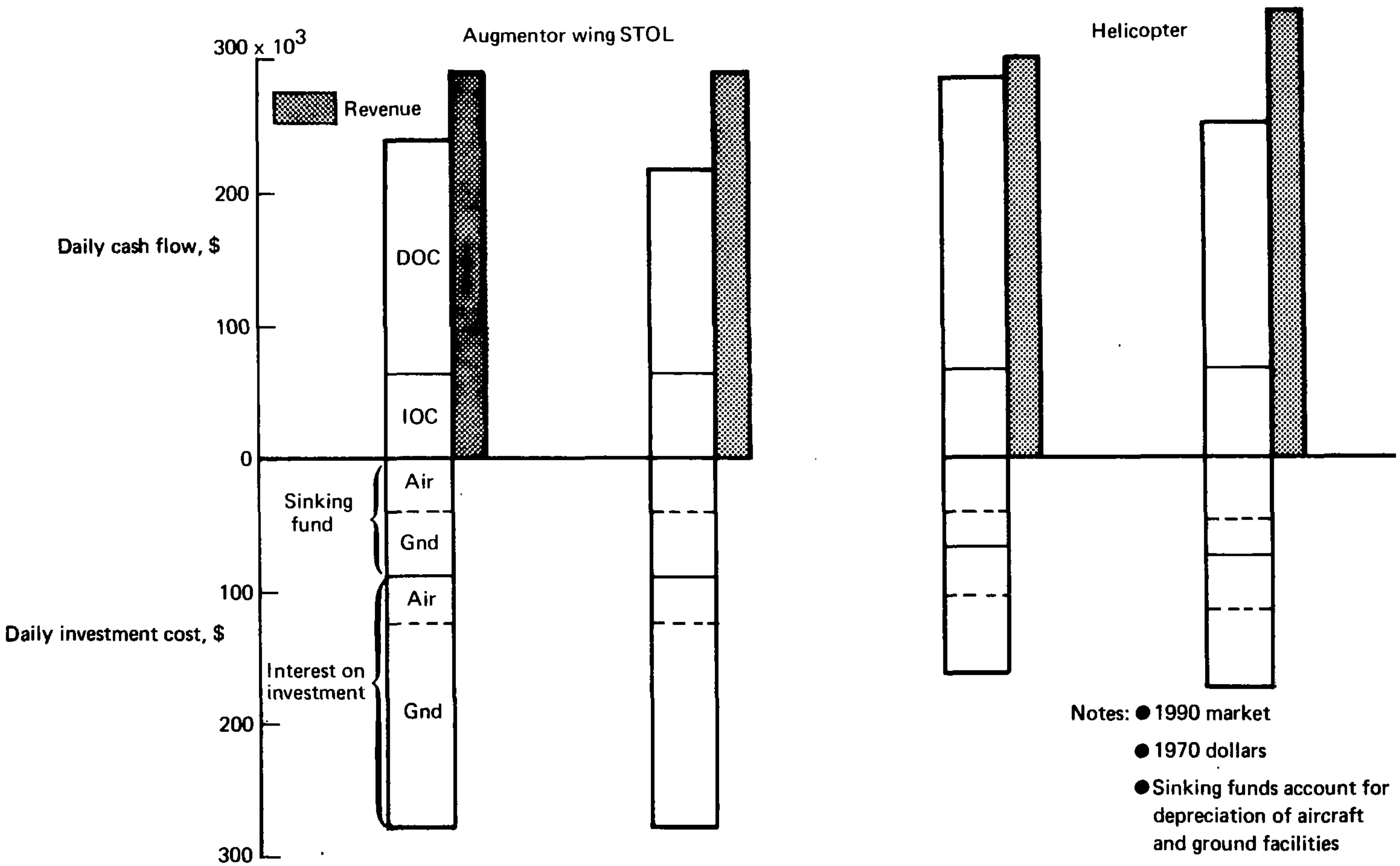
Vehicle	Helicopter	Augmentor wing STOL	Tilt-rotor VTOL	Augmentor wing STOL
Passengers	50	49	50	49
Technology	1975		1985	
Market	1980		1990	

FIGURE 5-20.–ANNUAL CASH FLOW D



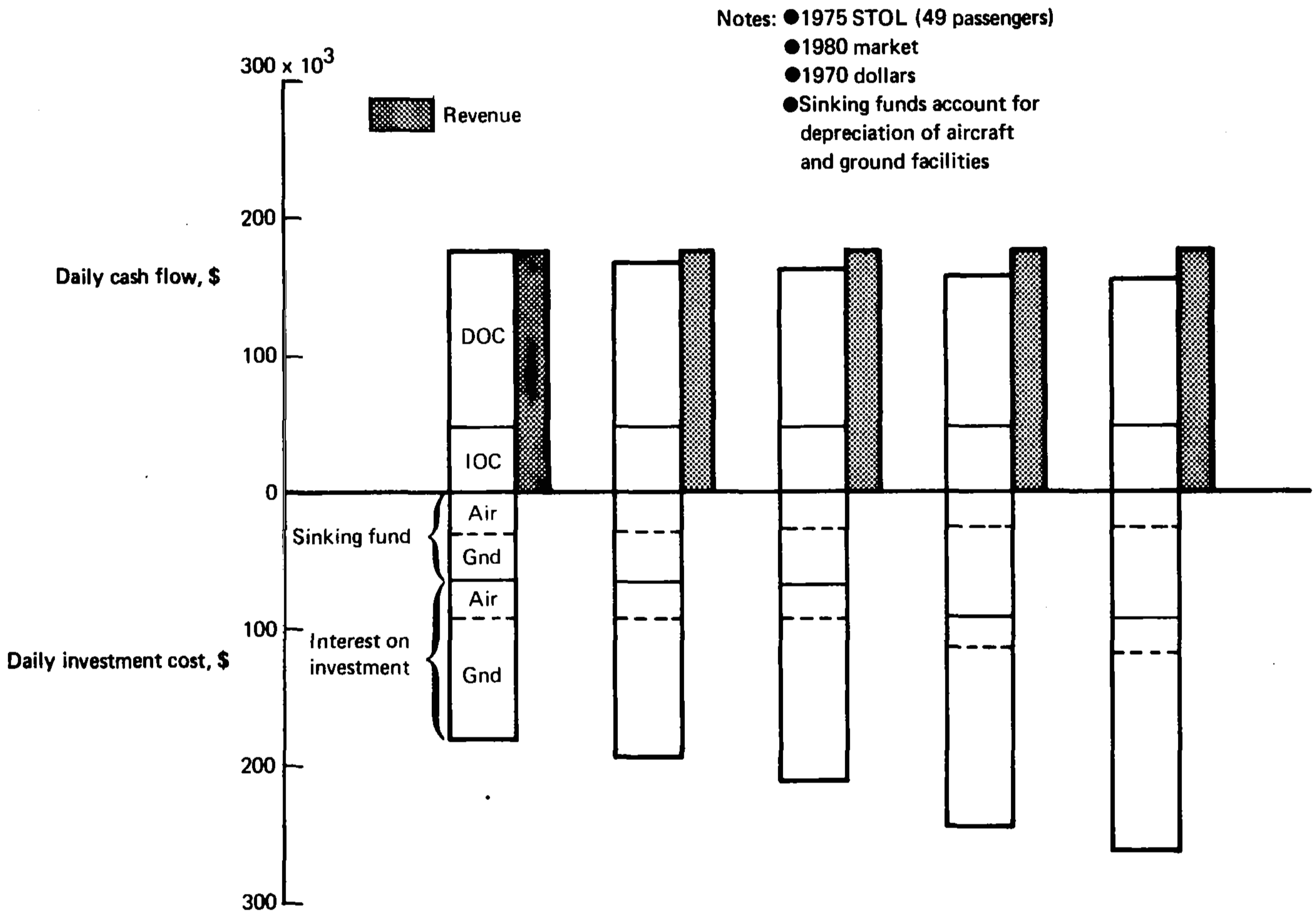
Vehicle	Helicopter	Augmentor wing STOL	Tilt-rotor VTOL	Augmentor wing STOL
Passengers	50	49	50	49
Technology	1975		1985	
Market	1980		1990	

FIGURE 5-21.–ANNUAL CASH FLOW E



Vehicle	Augmentor wing STOL		Helicopter	
Passengers	49		50	
Loss per passenger	$2.86	$2.57	$1.77	$0.95
Technology	1975	1985	1975	1985

FIGURE 5-22.–TECHNOLOGY SENSITIVITY



Field length, ft	1000	1500	2000	2500	3000
m	305	457	610	762	915

FIGURE 5-23.—FIELD LENGTH SENSITIVITY

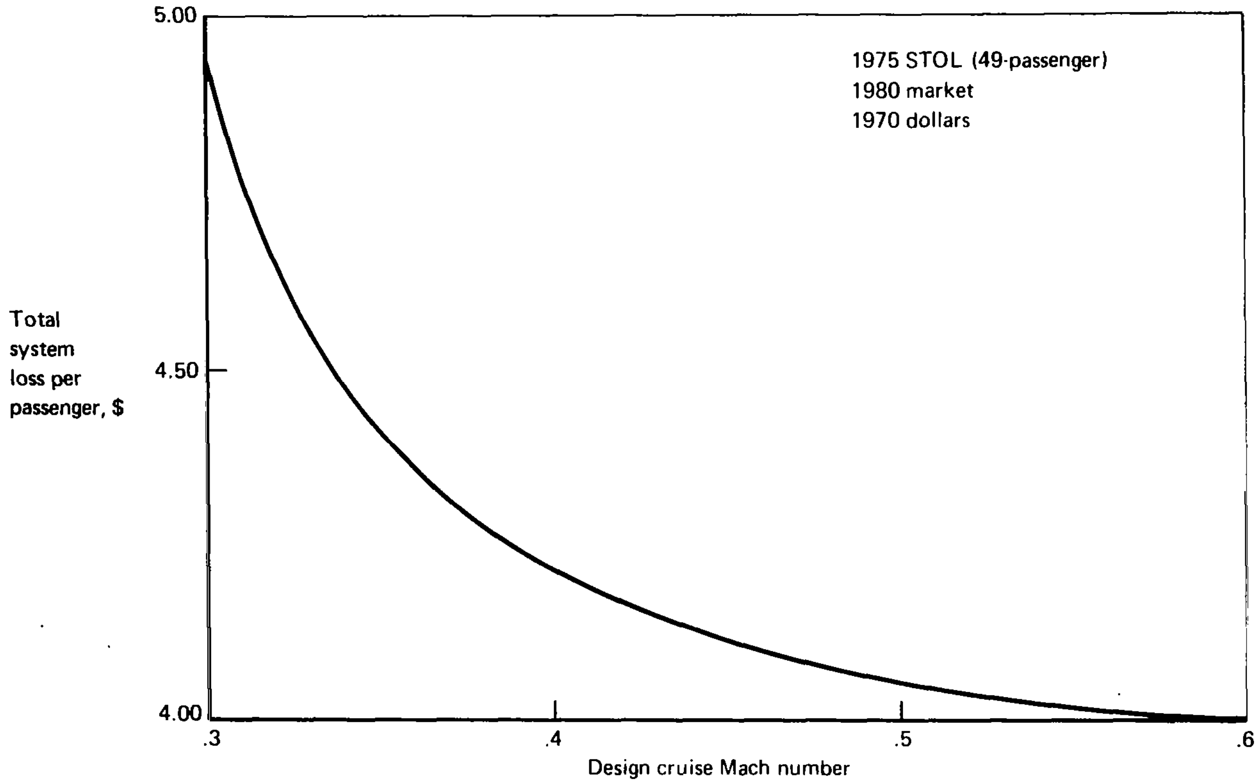


FIGURE 5-24.—DESIGN CRUISE MACH NUMBER SENSITIVITY

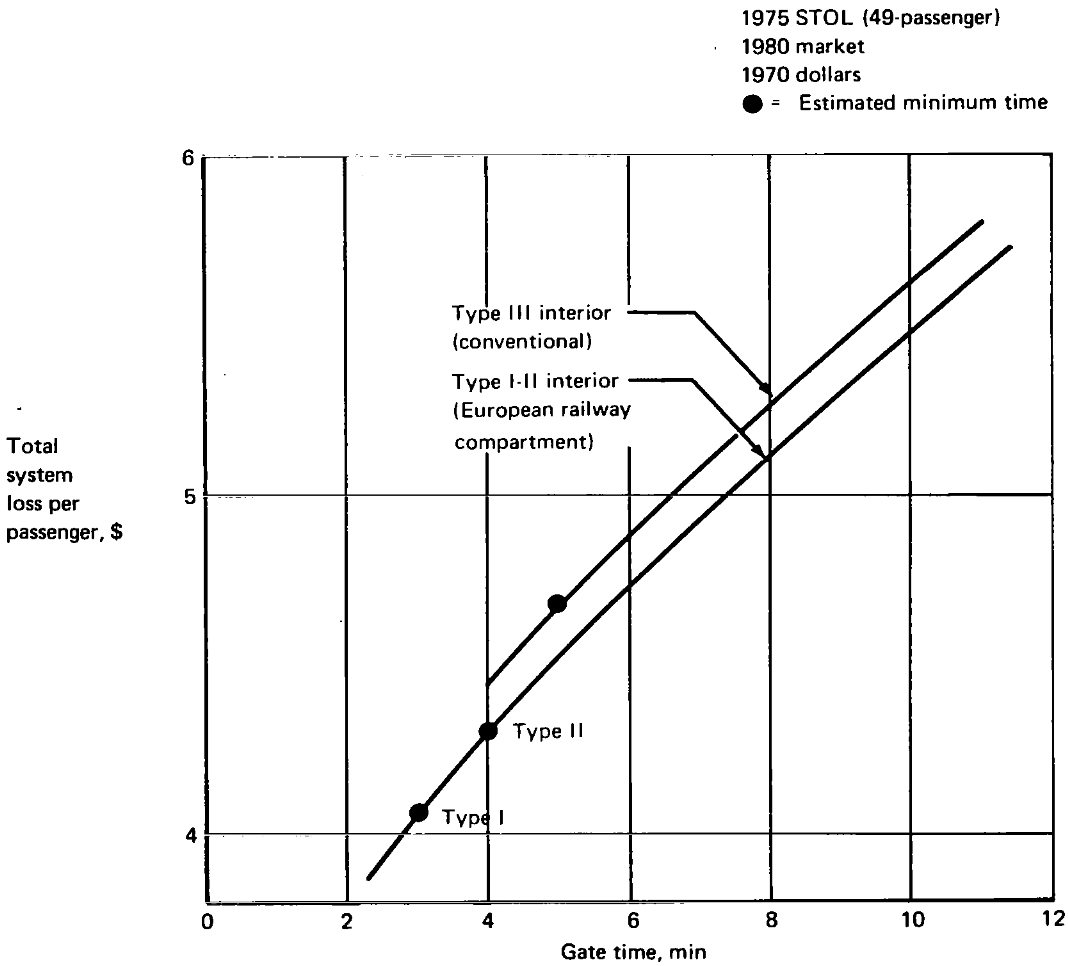
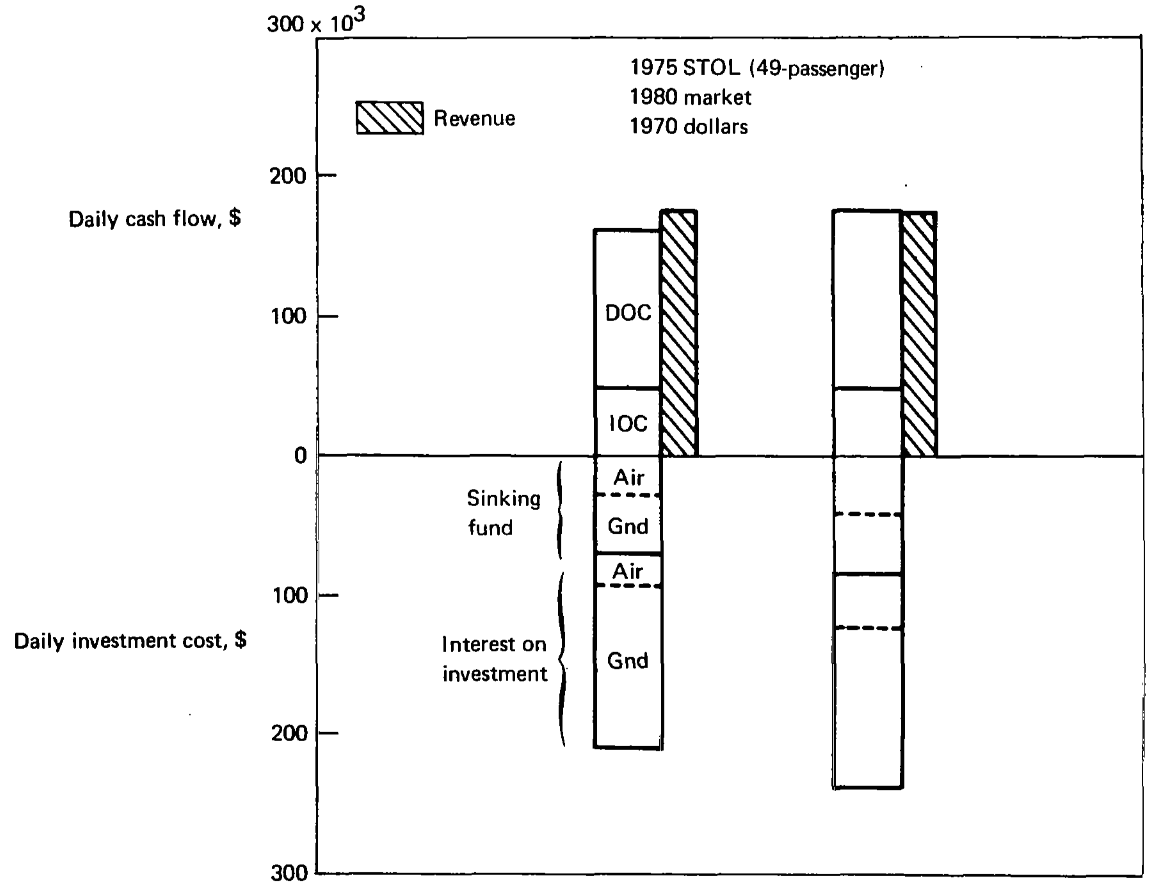


FIGURE 5-25.—GATE TIME SENSITIVITY



Production quantity	1500-2000	300-400
Loss per passenger	$4.05	$4.91

FIGURE 5-26.–PRODUCTION QUANTITY SENSITIVITY

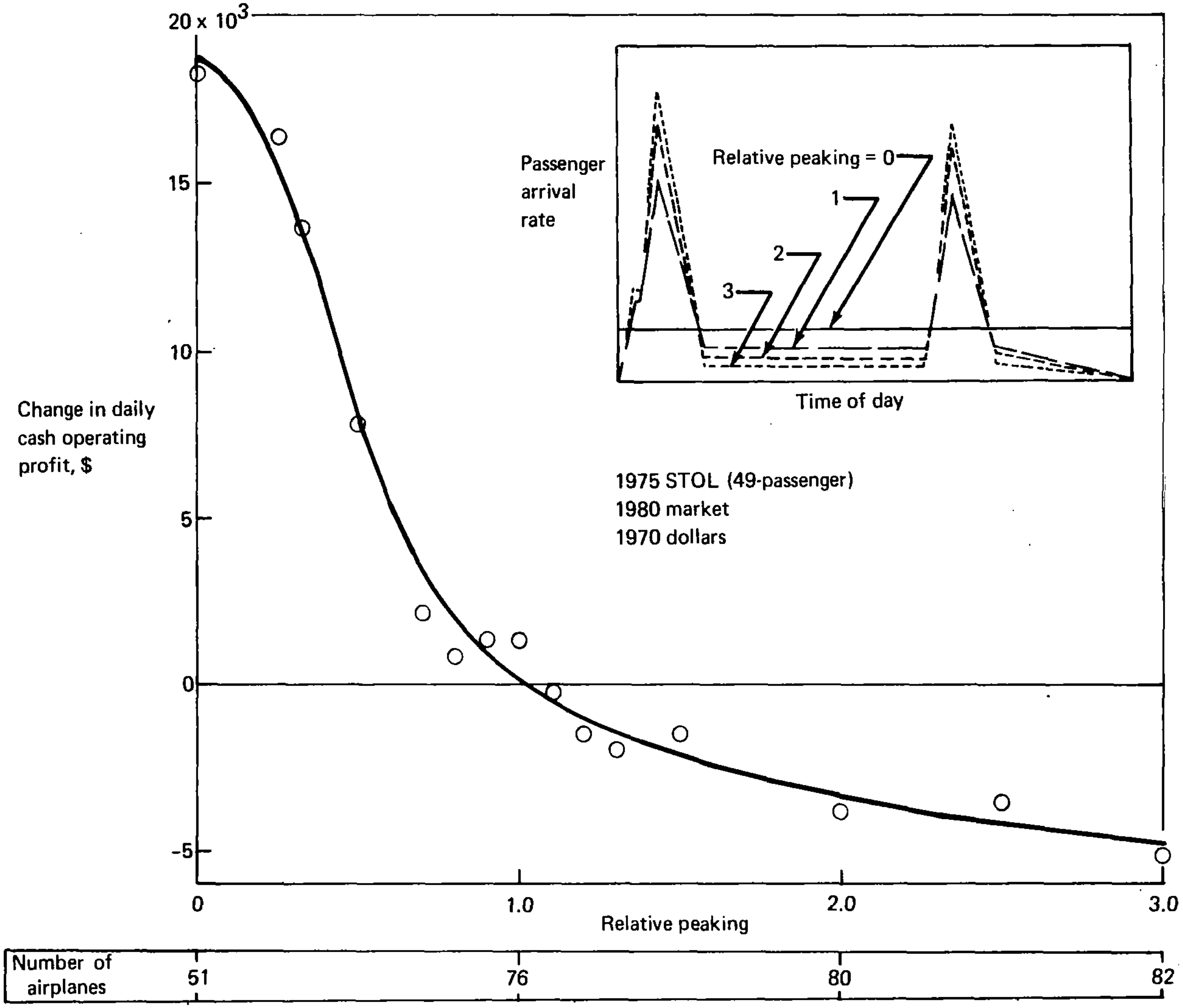
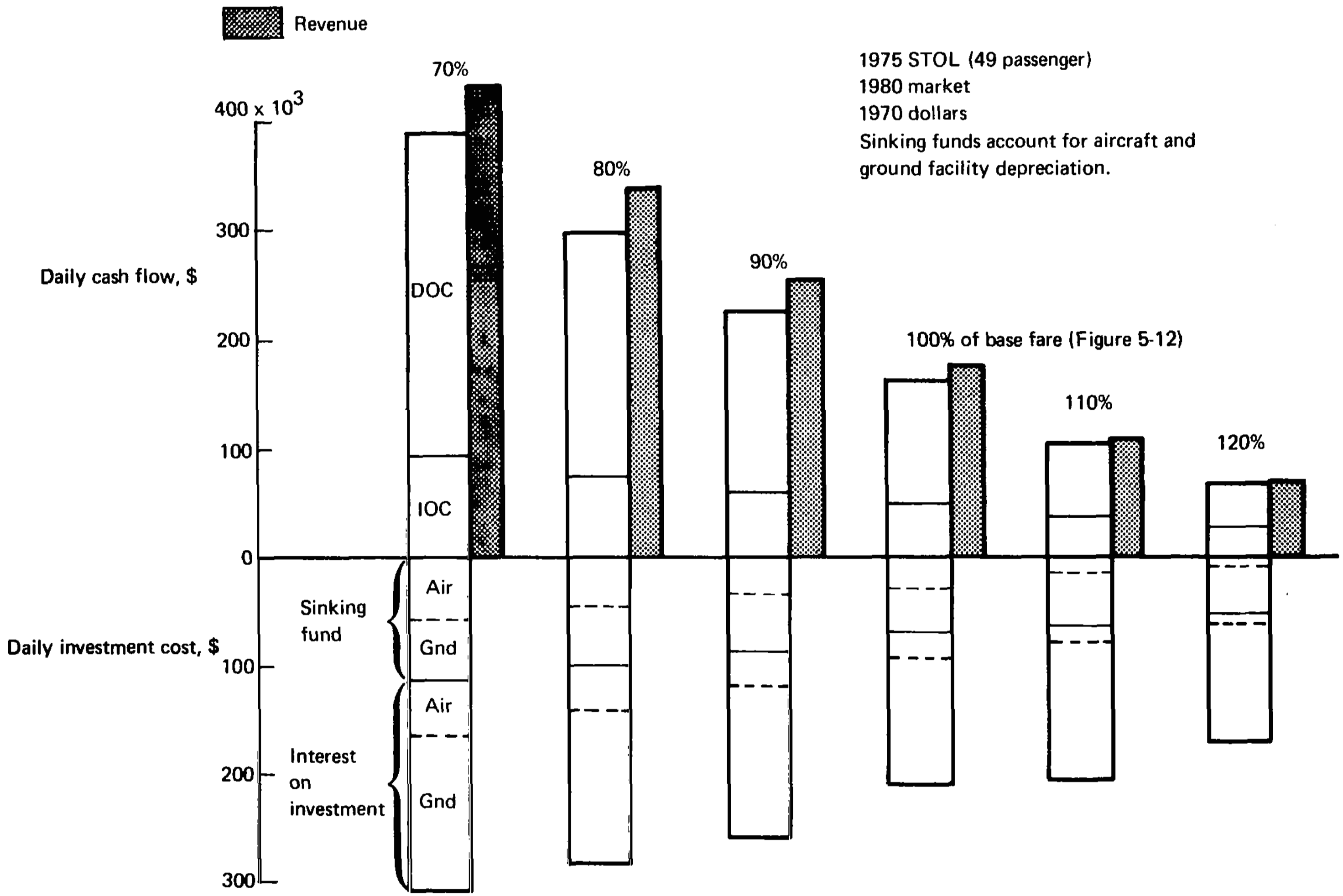
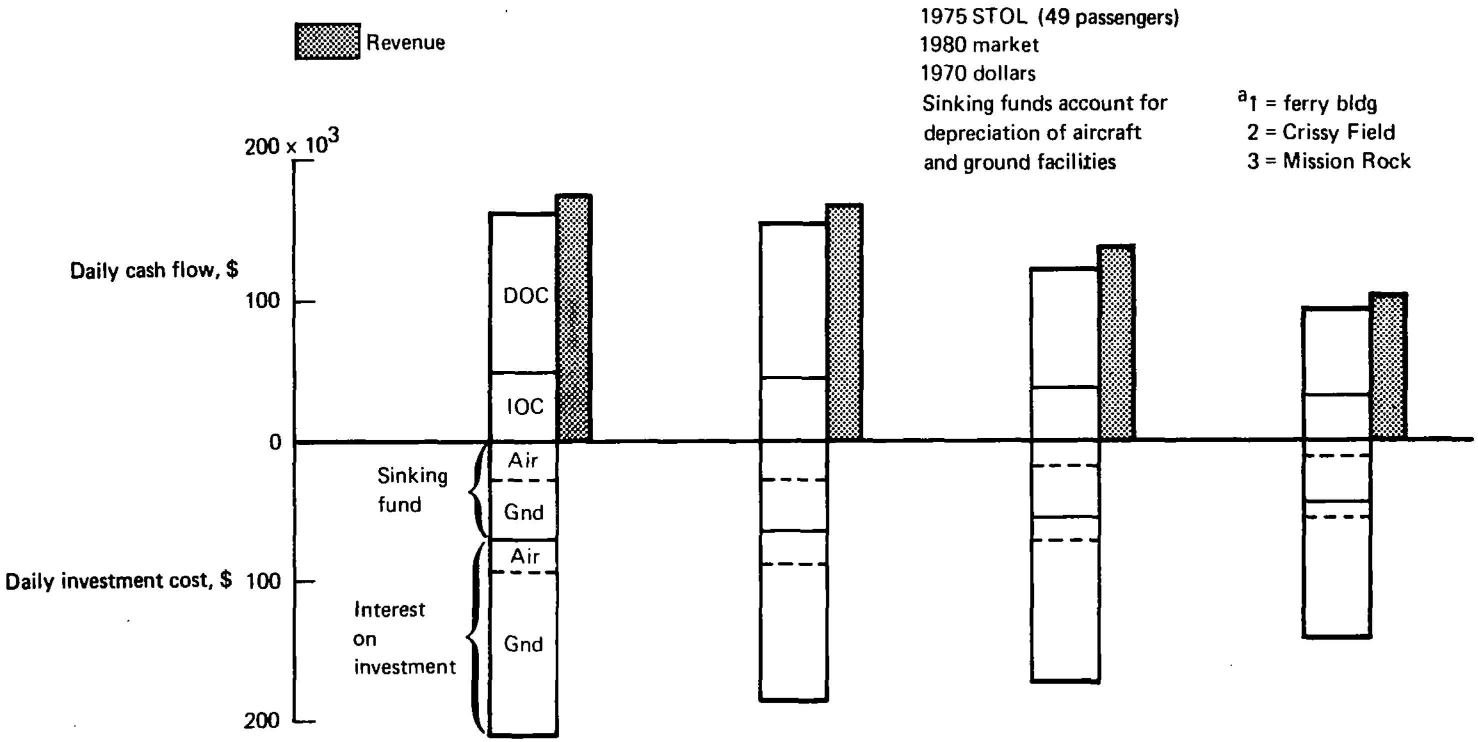


FIGURE 5-27.–PEAKING SENSITIVITY



Daily passengers	173 648	119 243	78 922	48 551	26 582	14 501
Average load factor	0.57	0.53	0.49	0.45	0.44	0.41
Loss per passenger	$1.53	$2.04	$2.92	$4.05	$7.66	$11.55

FIGURE 5-28.—FARE LEVEL SENSITIVITY



Ports eliminated[a]	None	1	1,3	1,2,3
Daily passengers	48 551	46 355	37 700	28 149
Loss per passenger	$4.05	$3.82	$4.19	$4.68

FIGURE 5-29.–SYSTEM SENSITIVITY TO ELIMINATION OF DOWNTOWN STOLPORTS

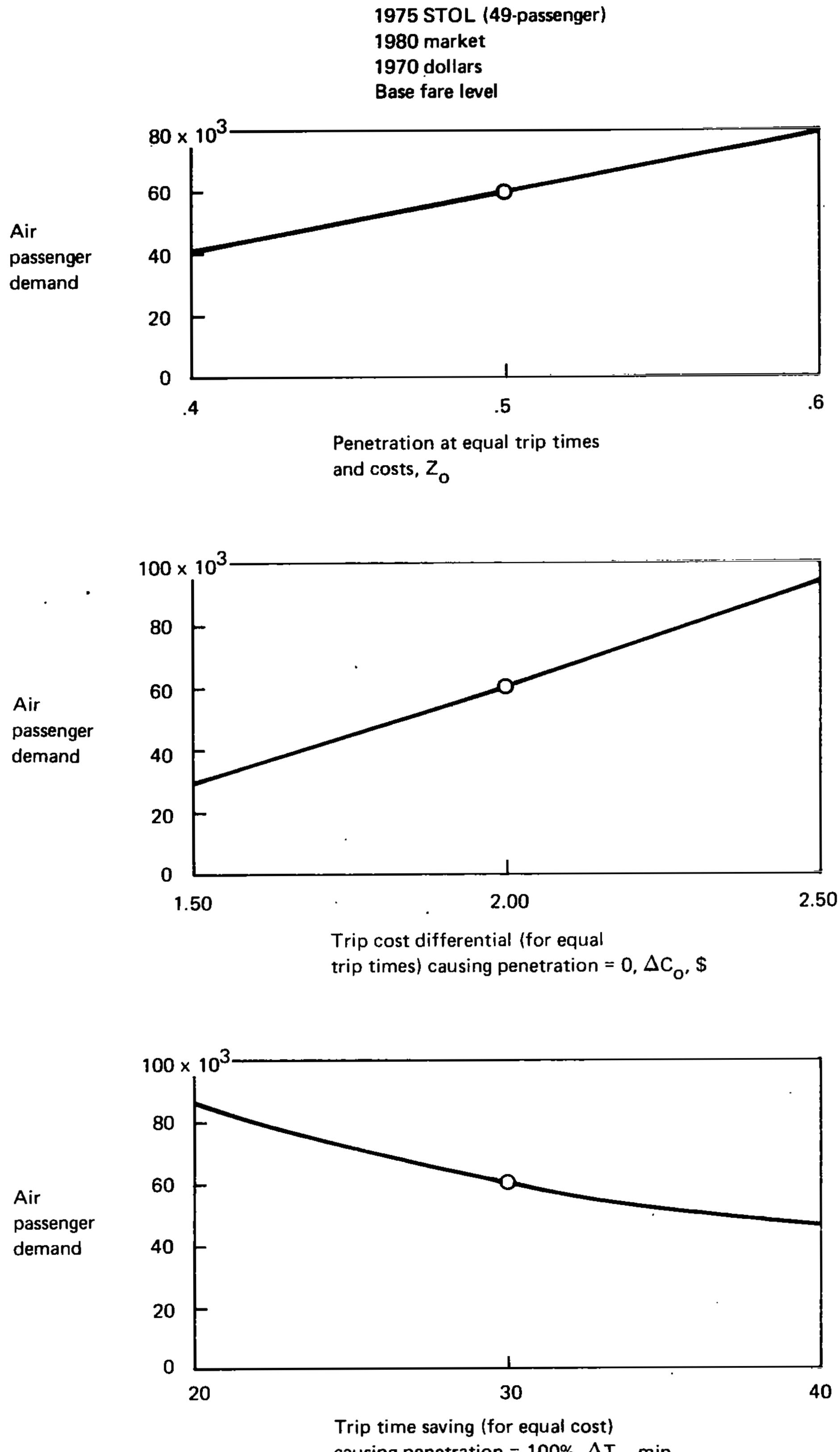
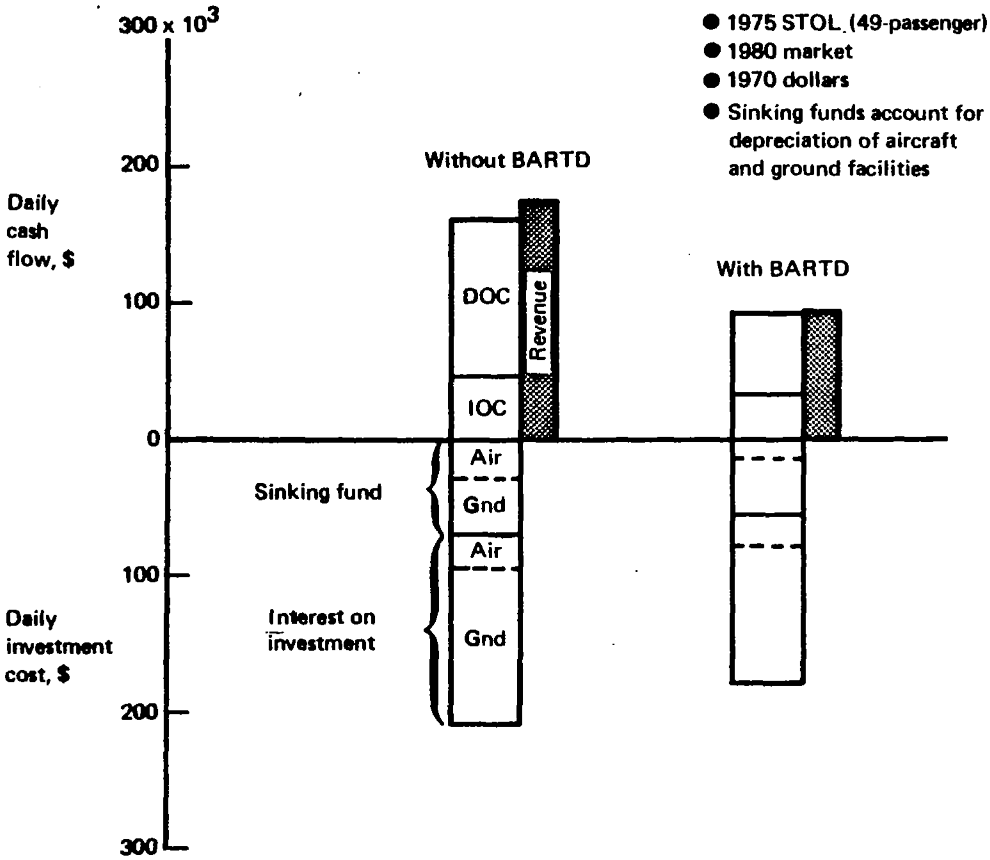


FIGURE 5-30.—MODAL-SPLIT INTERCEPT SENSITIVITIES



Loss per passenger	4.05	6.93

FIGURE 5-31.—EFFECT OF BARTD COMPETITION

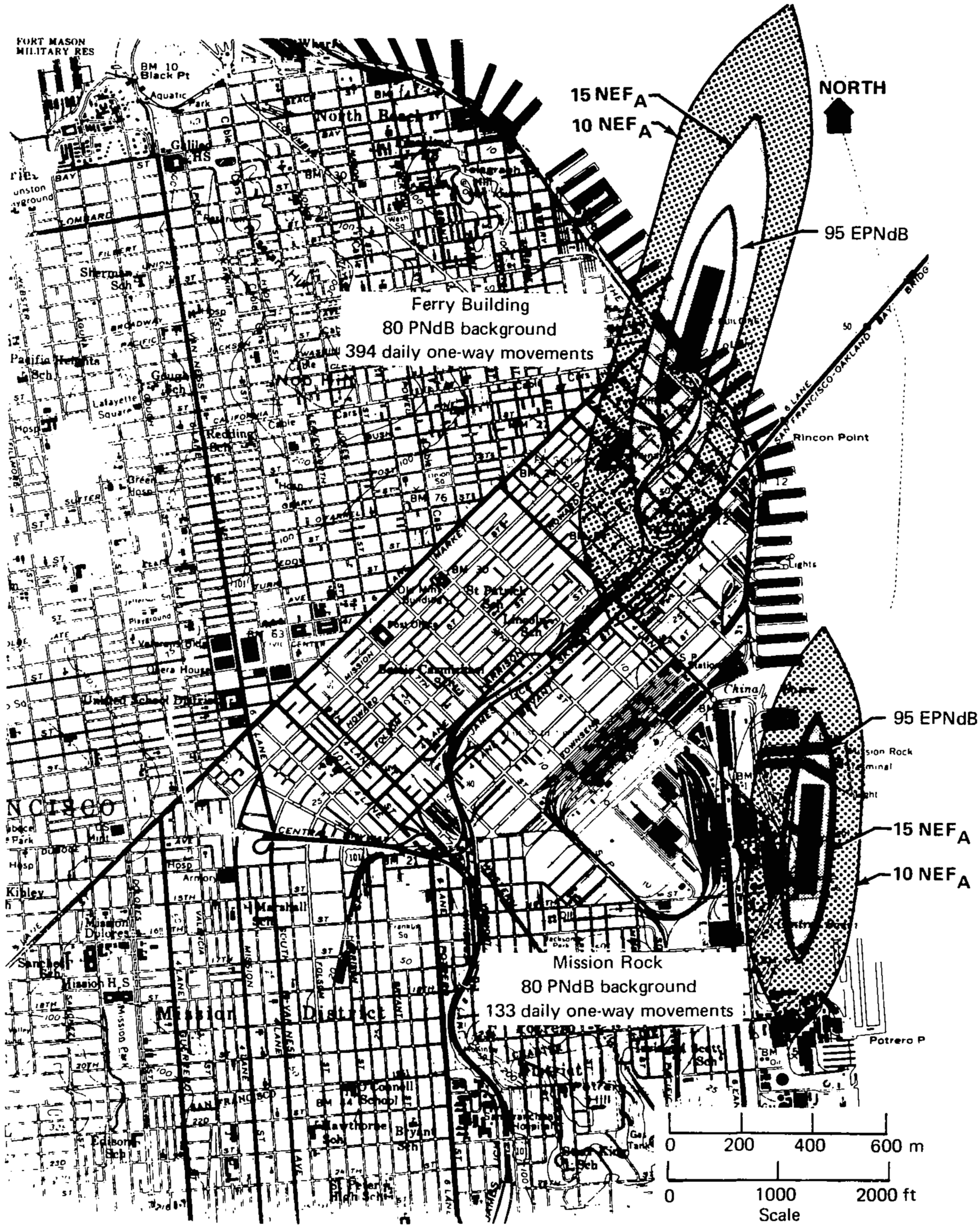


FIGURE 5-32.—COMMUNITY NOISE CONTOUR—STOL IN DOWNTOWN SAN FRANCISCO

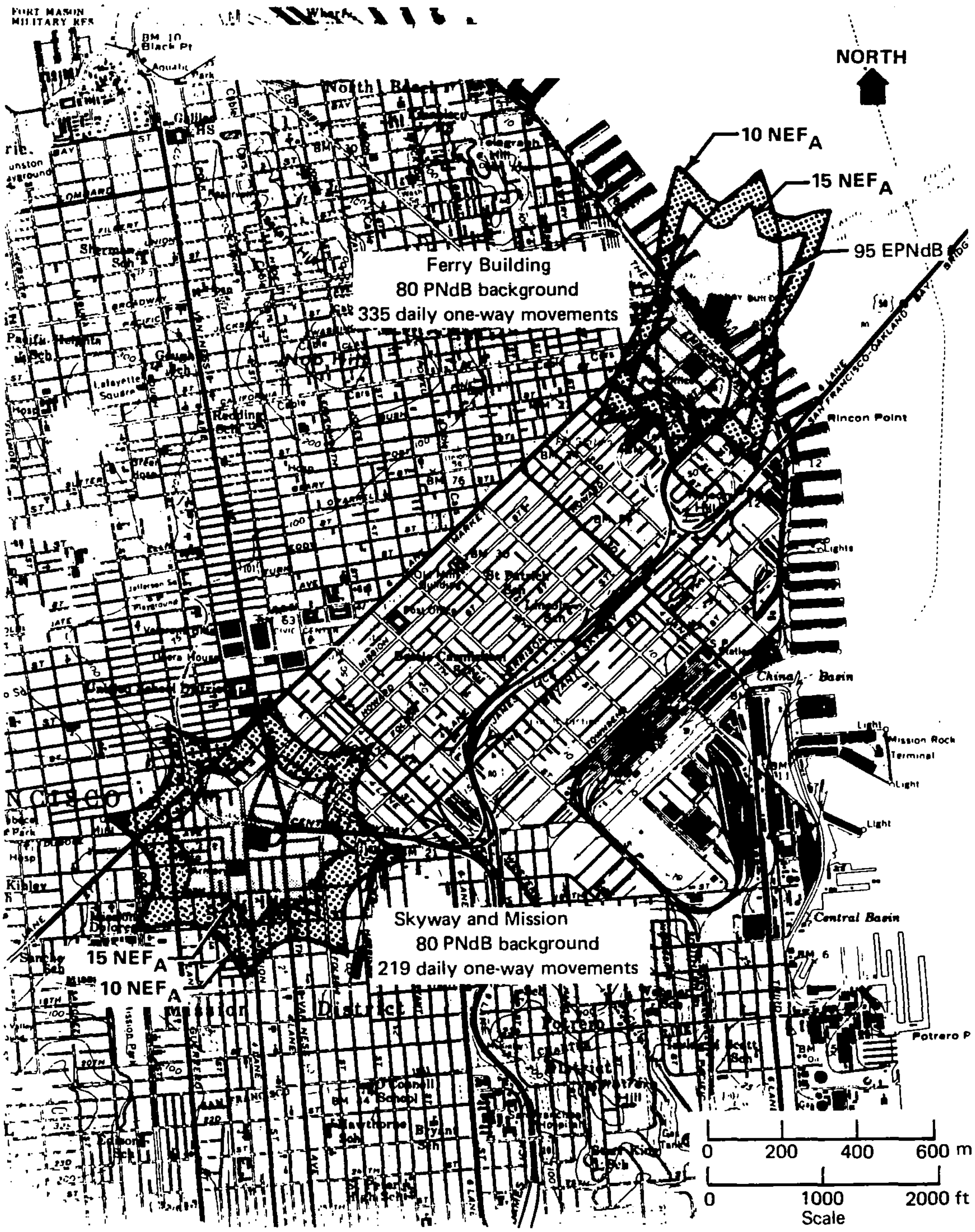


FIGURE 5-33.—COMMUNITY NOISE CONTOUR—HELICOPTER IN DOWNTOWN SAN FRANCISCO

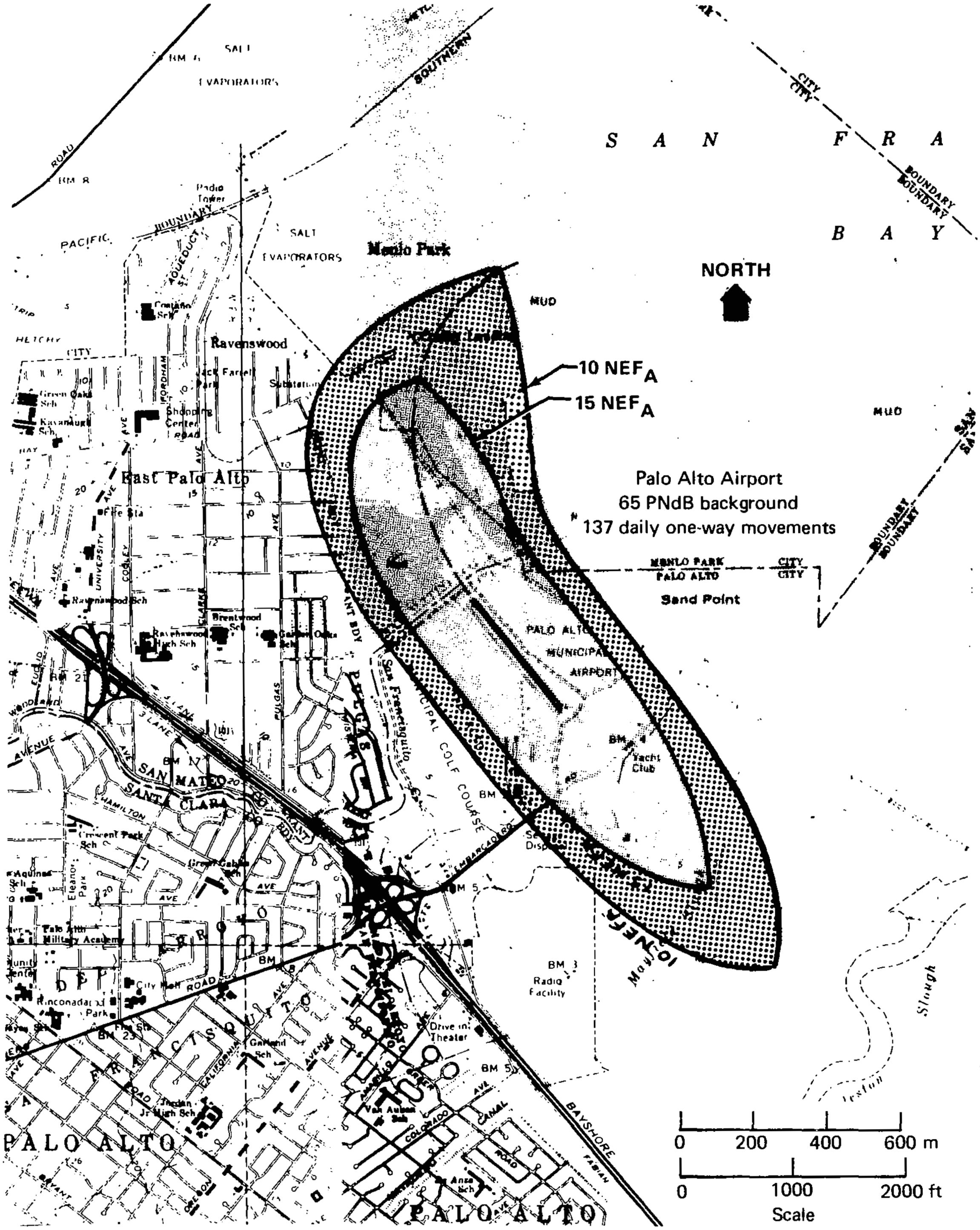


FIGURE 5-34.—COMMUNITY NOISE CONTOUR—STOL AT PALO ALTO AIRPORT

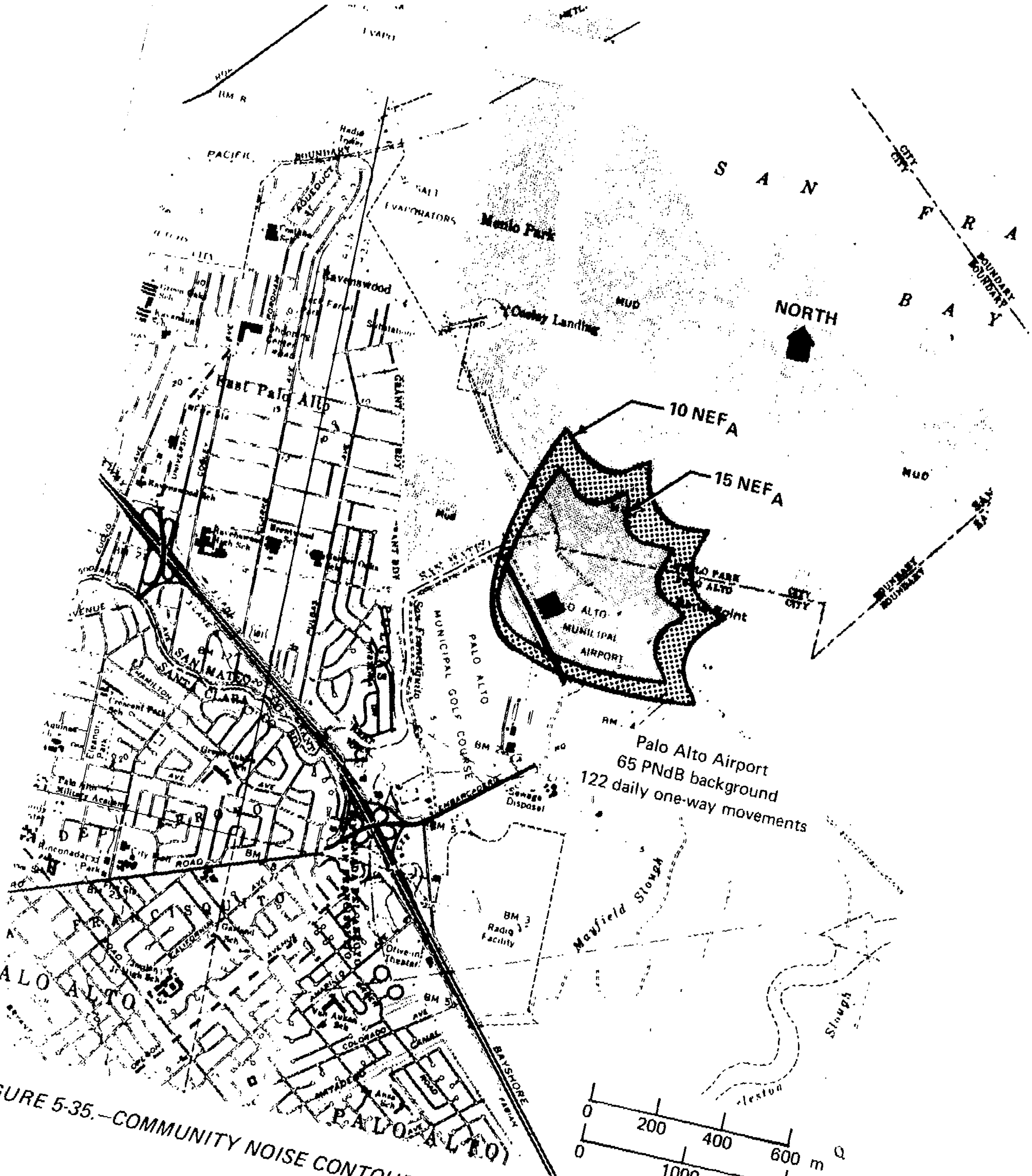


FIGURE 5-35.–COMMUNITY NOISE CONTOUR–HELICOPTER AT PALO ALTO AIRPORT

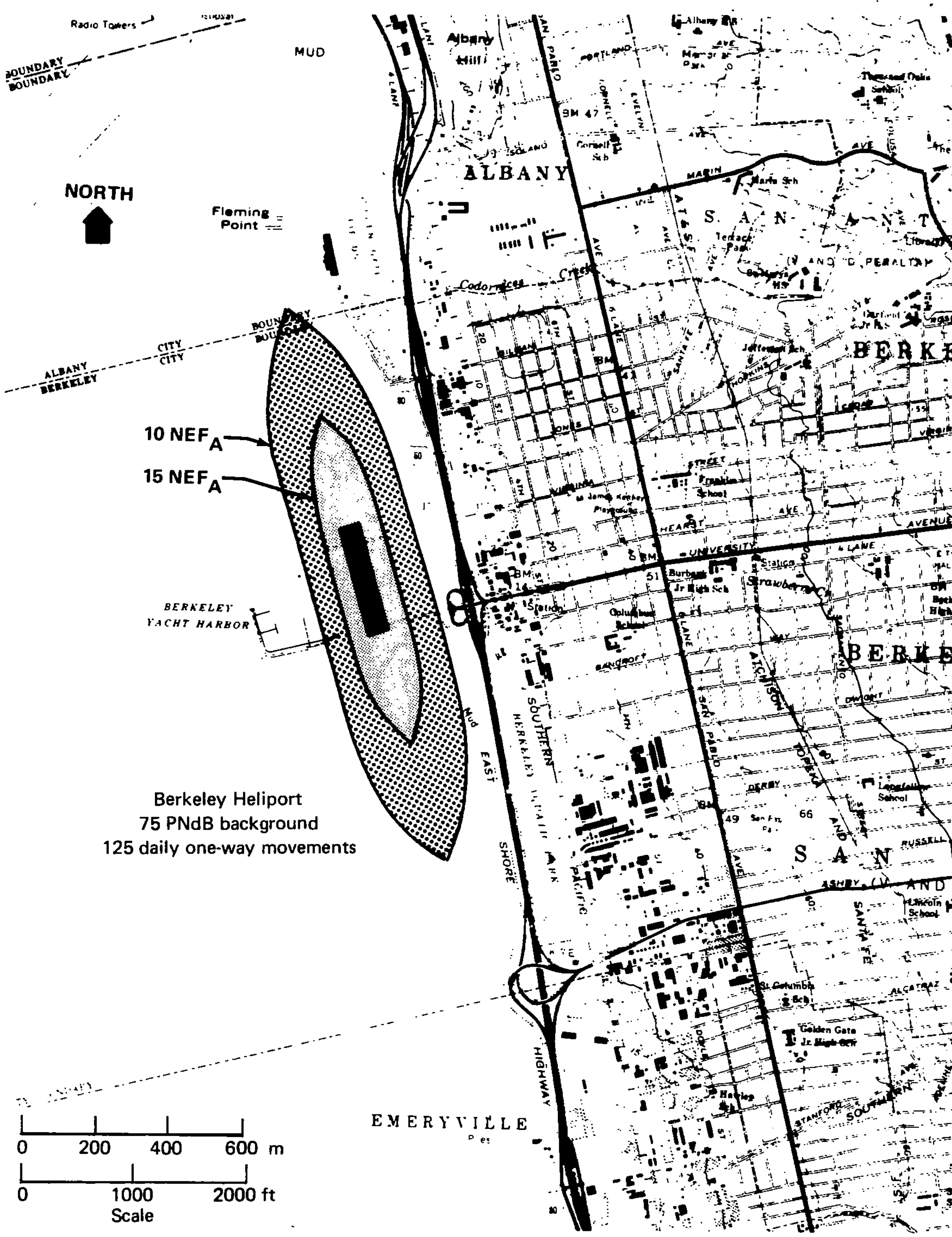


FIGURE 5-38.–COMMUNITY NOISE CONTOUR–STOL AT BERKELEY HELIPORT

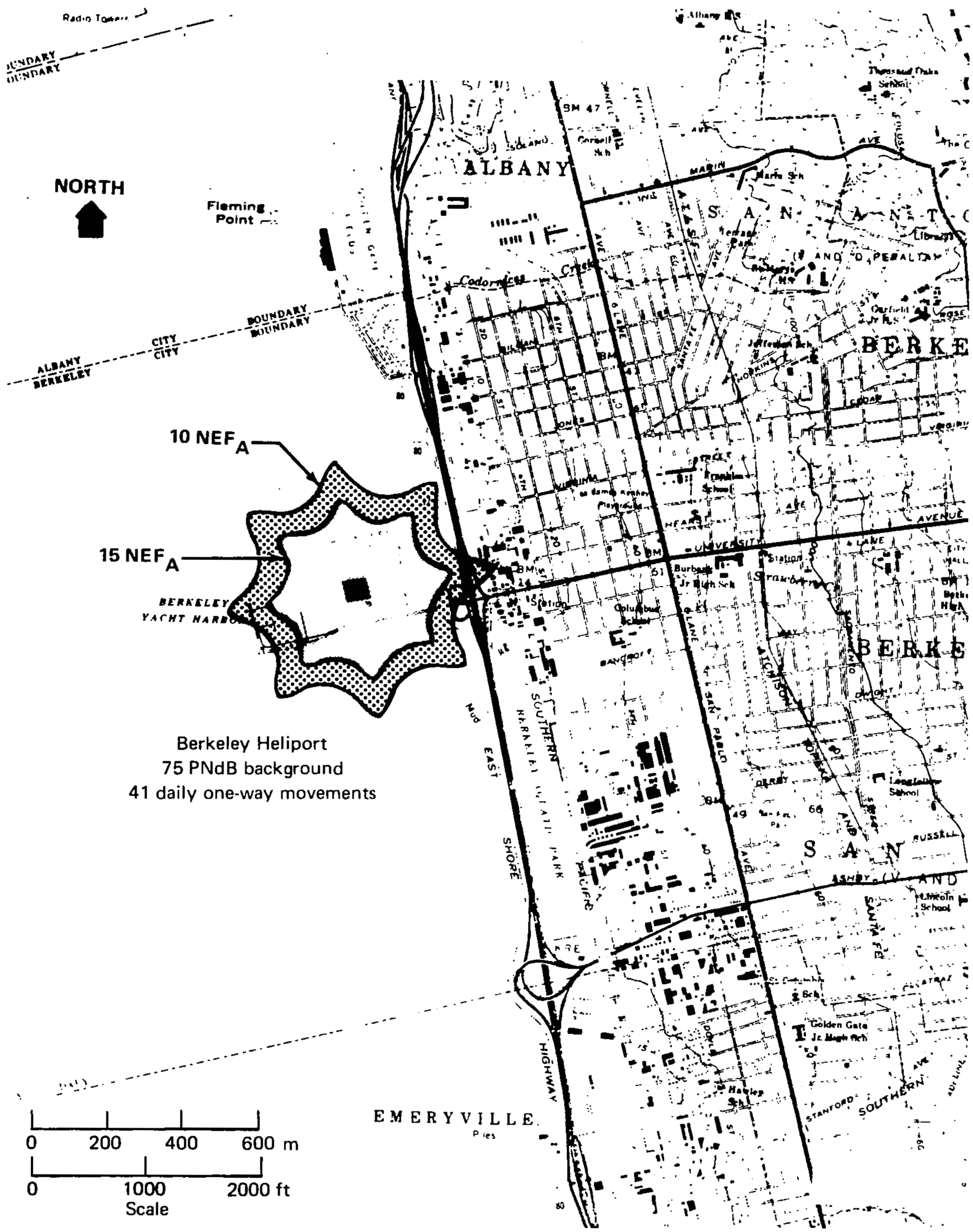


FIGURE 5-39.—COMMUNITY NOISE CONTOUR—HELICOPTER AT BERKELEY HELIPORT